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CONTENTS

Meteorological Acoustics 581
W. J. HUMPHREYS
Atmospheric Disturbances, or Static in Radio Telegraphy 619
L. W. AUSTIN
The Structure of the Photographic Image 631
C. E. KENNETH MEES
Anisotropic Liquids 651
J. STEPH. VAN DER LINGEN
A New General Law of Deformation 679
P. G. NUTTING
Ground-Plane Influence on Airplane Wings 687
A. F. ZAHM AND R. M. BEAR
Notes from the U. S. Bureau of Standards 695
Notes from the U. S. Bureau of Chemistry 705
Notes from the U. S. Bureau of Mines 709
The Franklin Institute Notes 713
Book Notices 720
Publications Received 724
Current Topics 618, 630, 678, 686, 694, 708, 712
Announcements . . . . . ix-xiii

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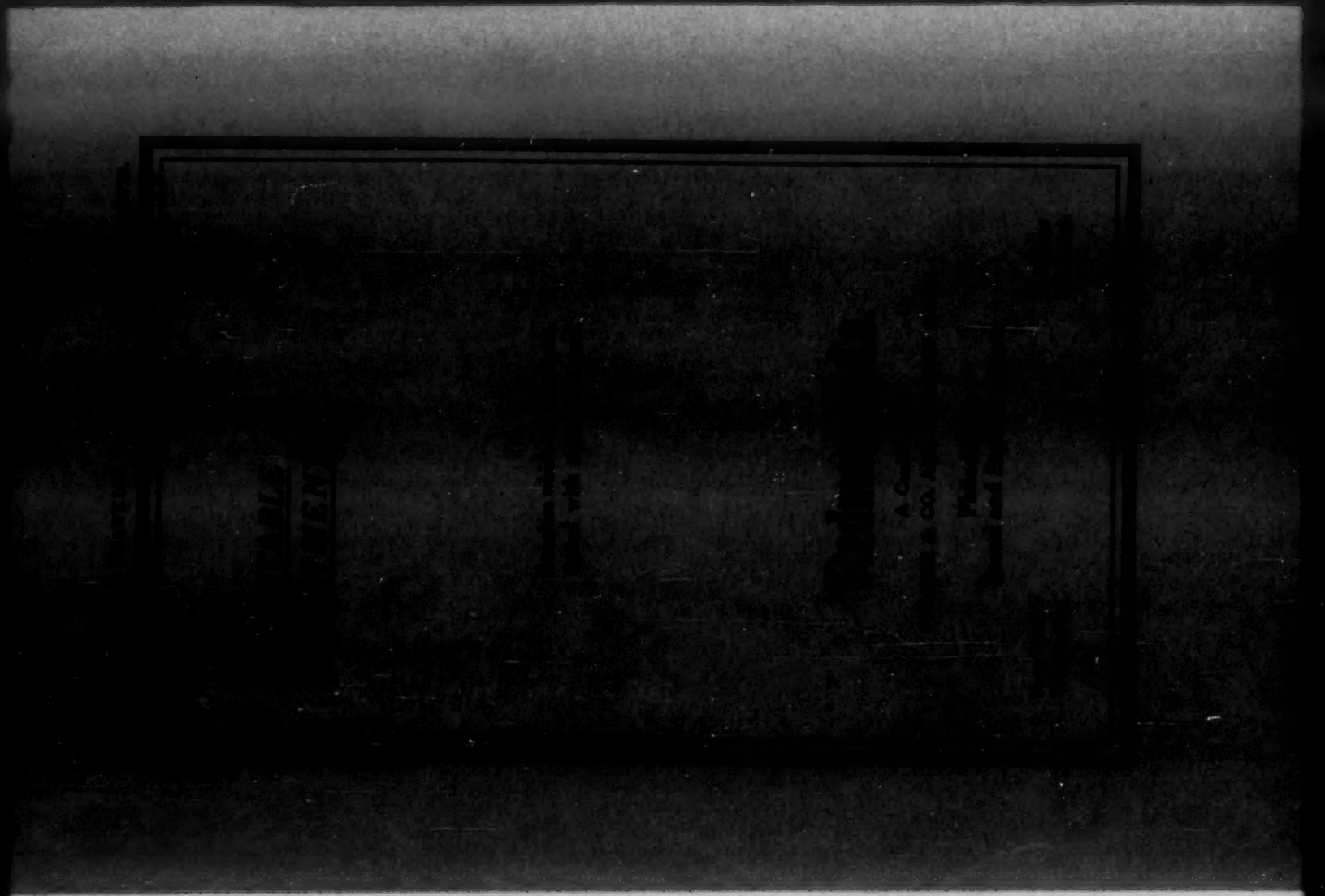

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METEOROLOGICAL ACOUSTICS.*

BY
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CHAPTER I.

METEOROLOGICAL EFFECTS ON SOUND.

Introduction.

METEOROLOGICAL acoustics is concerned with every sound of a distinctly meteorological origin, such as the humming of telegraph wires, the "roaring of the mountain," the rumbling of thunder, and the like; and with every effect meteorological conditions have on the travel, distribution, and audibility of sound. In short, it treats of meteorological sounds and of meteorological effects on sound.

Nature of Sound.—The term "sound," as used in the science of acoustics, means either an external disturbance or a sense impression. In the more restricted field of meteorological acoustics, it has only the former of these meanings; the sensation being referred to merely as evidence of the presence and nature of a disturbance in the external medium.

Now, everyone knows: (*a*) by observation, that a tuning fork, bell, violin string, and the like, produce sound only when vibrating;

* Communicated by Dr. E. D. Ball, Assistant Secretary of Agriculture.

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(*b*) by observation, that the hammer is seen to strike, the gun go off, the lightning flash, and innumerable other abrupt causes of sound to occur, before the sound itself is heard, and that this time interval increases with the distance of the observer; (*c*) by experiment, that the sound of a bell, say, mounted on an acoustical insulator within an air pump receiver grows fainter and fainter to extinction as the exhaustion of the receiver is progressively increased.

From these three facts it is obvious that objective sound, or sound in its physical aspect, consists of traveling disturbances of some kind in a material medium. If this medium is the atmosphere (or any other fluid) it is further obvious that the disturbances in question consist of compressions and rarefactions, for the atmosphere has no tendency to recover from distortion of any kind save that of volume alone—no tendency to recover from twist or bend, but a resistance to change of volume that increases with the ratio of that change to the initial volume.

Seeing Sound.—Since sound consists of condensations and rarefactions of the atmosphere traveling outward from the source, and since light is unequally refracted by air of different density, it would seem possible to see, and perhaps even to photograph, the front of a sound pulse. And this has, indeed, often been realized. The outermost sound shell, produced by the firing of a cannon, for instance, has repeatedly been seen sweeping across the sky, and over clouds, like a narrow fleeting shadow. Similarly the initial condensation wave caused by an electric spark has given numerous beautiful and instructive photographs, of which Fig. 1, from Doctor Foley's remarkable collection,[1] showing both the primary wave and its reflection from a flat surface, is an excellent example.

Velocity of Sound.

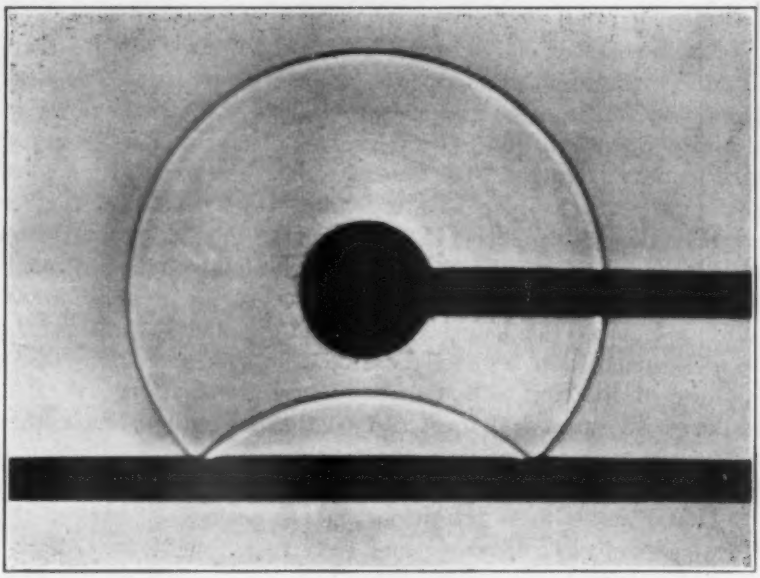
Velocity of Sound in Still Air.—As stated above, many simple observations show that sound travels through the air with moderate velocity—faster than a mile a minute, and slower than a mile a second. Just what this velocity is might be determined by careful experiment over a large range of temperatures, pressures, humidities, and other factors, and its relation to each empirically determined. But while this has been done to some extent, the collection of an adequate amount of such data would require long

[1] *Phys. Rev.*, 35, p. 373, 1912.

and tedious work and the results in the end would be only empirical and not rational. Hence it seems desirable to logically derive equations that show the exact and necessary relation of the velocity of sound to each of the several factors upon which it depends.

The following method of computing sound velocity is essentially that of Rankine.[2] It may not be so mathematically elegant as the "velocity potential" method, used by Lord Rayleigh,[3] for

FIG. 1.



Photograph of sound waves—incident and reflected. (A. L. Foley).

instance, but it has the great advantage of revealing, rather than concealing, the physical processes involved.

Consider an ordinary sound wave (great explosions which result in additions to the atmosphere, and hence require a modified treatment, are excluded) at some distance from its origin, traveling through the atmosphere. As above explained, this disturbance must consist of longitudinal motions of the air particles in the line of travel of the sound, resulting in alternate compressions and rarefactions. This follows from the fact that the atmosphere

[2] *Phil. Trans.*, 160, p. 277, 1870.
[3] "Theory of Sound," ii, p. 15.

is elastic only to changes of volume and not to twists or bends. Furthermore, it is clear that these sound excursions of the air particles are small—not even leaves visibly quiver as any ordinary sound passes—and the pressure changes comparatively slight, too slight indeed to be felt.

Clearly an atmospheric wave of any form, harmonic or otherwise, can be made to progress unchanged through air at any given speed by applying to each particle a proper external force, directed along the line of travel, in addition to the internal force already acting on it.

Let the external force be X per square centimetre in the direction of propagation, that is, per square centimetre of a plane wave front over which, of course, all particles are in the same vibration phase, and hence subject to exactly equal forces; and let X vary in such manner from phase to phase as to keep the form of the wave unchanged and to give it a uniform velocity v. To further simplify the problem, consider an imaginary tube of unit cross section, parallel to the line of propagation and extending through the wave front slightly into the undisturbed region on one side and more or less into the disturbed region on the other. Let this tube be fixed in position, and let the atmosphere flow past it exactly opposite in direction to that of the sound propagation. That is, let the sound waves or that arbitrary portion of a single one, within the tube, though continuously affecting new material, be absolutely fixed in position and condition.

What, under these conditions, are the relations between the forces involved, internal and external, and the deductions therefrom?

Since the quantity and condition of the air within the tube is constant it is obvious that its momentum is also constant, and also, under the given conditions, wholly along the line of propagation. Hence the momentum entering the front of the tube during a given interval, one second say, is equal to the momentum leaving it during the same interval. This momentum *per second* consists of two parts, *a*, the mass entering, or leaving, per second, times its velocity, and, *b*, the pressure upon this mass at the place of entrance or exit, respectively—force is equal to mass times acceleration, which is equal to momentum produced per second in the direction of the force.

Let, now, P be the pressure in the undisturbed atmosphere, and

hence at the front end of the tube; $P \pm p$ the pressure at the rear end of the tube (p being either positive or negative, owing to whether this end of the tube is in the compression or rarefaction portion, respectively, of the wave); v the velocity of entry of air of density ρ into the tube; $v \mp u$, and ρ_1 the velocity and density, respectively, of the air as it leaves the tube; and X the assumed sustaining external pressure, constant at each particular phase, and thus constant at the exit end of the tube.

Hence, the momentum entering the tube of unit cross section per second is, if m is the mass

$$mv + P$$

Similarly, the momentum leaving the tube per second is, since the mass within the tube cannot change,

$$m(v \mp u) + P \pm p + X$$

But the two momenta are equal, therefore

$$mu = \rho vu = p \pm X$$

If, now, v is so chosen that

$$\rho v = p/u, X = o$$

and the sound moves on without the aid of any external force with the velocity

$$v = p/\rho u \qquad (1)$$

As above explained,

$$\rho_1 (v \mp u) = \rho v$$

and, if the air remains isothermal,

$$(P \pm p)/\rho_1 = P/\rho$$

Hence, neglecting pu,

$$u = pv/P$$

and, substituting in (1),

$$v = \sqrt{\frac{P}{\rho}} \qquad \text{(Newton)}$$

Or, if the compressional changes take place adiabatically,

$$ku = pv/P$$

in which k is the ratio of the specific heat of the air involved at constant pressure to its specific heat at constant volume, and

$$v = \sqrt{\frac{kP}{\rho}} \qquad \text{(Laplace)}$$

Whether the velocity of sound is in accordance with Newton's equation, or Laplace's, or has, indeed, some distinctly intermediate value (it cannot be outside these theoretical extremes) can, of course, be tested by direct experiment. But here, too, theory is a great help in that it shows[4] the impossibility of a velocity appreciably different from one or the other of the extremes. The nonmathematical form of this reasoning (Stokes gives both) is substantially as follows:

Let an airtight, frictionless, piston oscillate so slowly in a cylinder with thermally conducting walls that the temperature of the enclosed air remains constant. Clearly, then, at each given position of the piston the pressure is the same during expansion as during compression, and the process is without net loss, or gain, of energy. Similarly, if the reciprocal motion of the piston is so rapid that no heat is lost during compression, nor gained during expansion, the pressure, though different from its former value, is again constant for each given position of the piston, and hence the total external work zero per cycle.

If, however, the speed of the piston is such that some heat is passed, but not enough to maintain a constant temperature, the pressure at each point will be greater during compression than during expansion, and the process can be maintained only at the expense of external work. Under these conditions, therefore, the sound would be damped out far more rapidly than is the case in nature.

Actually, sound waves are so fleeting (only those of the baser tones require more than a hundredth of a second to pass) that the slight pressure changes they produce are all but absolutely adiabatic. Hence, to an extremely close approximation,

$$v = \sqrt{\frac{kP}{\rho}} = \sqrt{\frac{1.40\,P}{\rho}} \qquad (2$$

It should be noted here that since neither u, p, nor ρ_1, the only factors affected by either the amplitude or frequency of the vibrating air, enter into equation (2), therefore the velocity of sound is independent alike of both loudness and pitch—the same for all sounds of whatever origin.

Relation of the Air to Sound Velocity.—From equation (2) it is likewise clear that all meteorological changes that alter the value

[4] Stokes, *Phil. Mag.*, 1, p. 305, 1851.

of k, or the ratio of P to ρ, or both, affect also the velocity of sound; and that it is independent of every other such change.

Changes in pressure, therefore, do not alter the velocity of sound. They obviously do not affect the value of k, and, by proportionately varying ρ, leave the ratio of P to ρ constant. On the other hand, variations in the temperature do affect the velocity of sound. In fact, this velocity is directly proportional to the square root of the absolute temperature, T, as is obvious from the fact that when P and k are constant (k constant implies same composition), ρ is inversely proportional to T. Similarly, changes in the absolute humidity also affect the velocity of sound, since they slightly alter the value of k.

The value of k for dry air is 1.40, very closely. Its value for water vapor is not accurately known for ordinary out-door temperatures, but appears to be 1.30 roughly. Presumably, therefore, in nature

$$k = 1.40 - 0.1\, e/P$$

approximately, in which P is the total atmospheric pressure and e that portion of it due to water vapor.

In terms of the reading of the barometer

$$P = (B - .378\, w)\, g\, \delta$$

in which B is the reduced total height of the barometer, w the reduced height due to the water vapor, g and δ the standard gravity acceleration, and mercury density, respectively.

Finally, if ρ_0 is the density of dry air at 0° C. and when the reduced height of the barometer is 760 mm., then

$$\rho = \rho_0 \frac{(B - .378\, w)}{760\ (1 + at)}$$

in which a is the coefficient of gas expansion per degree Centigrade at 0° C., and t the temperature, as read on the Centigrade scale.

On substituting these several values in the equation for the velocity of sound it appears that, in terms of centimetres per second,

$$= \sqrt{\frac{76\, g\, B\, \delta\ (1 + at)\ (1.40 - 0.1\, w/B)}{\rho_0\ (B - 0.378\, w)}}\,.$$

For dry air at 0° C. this reduces to

$$v = \sqrt{\frac{76\, g\, \delta\ (1.40)}{\rho_0}} = \sqrt{\frac{76 \times 980.665 \times 13.5951 \times 1.40}{0.0012930}}\,,$$

or 331.23 metres per second, which is in close agreement with observations.

The effect of dust, smoke, fog, or any other such foreign substance in the atmosphere, on the velocity of sound is not well known. Presumably, however, the values of both k and ρ, and through them the velocity in question, are altered by all such things. But as the aggregate mass of any such substance is invariably quite small in comparison to that of the atmosphere in which it floats, and since it plays the rôle of a gas to only a limited extent, its effect on this velocity must always be minute, and for most purposes entirely negligible.

Doppler Effect.—Many, if not most of us, have often noticed the change in the pitch of a locomotive whistle, or bell, as the train passed rapidly by us; and also the similar change in pitch of a bell, or other sounding object, as we were carried rapidly past it. This phenomenon, known as the Doppler effect, and dependent on the finite velocity of sound, is easily explained.

Let v be the sound velocity; n the vibration frequency, λ the wave-length, and u the velocity of the sounding body towards, or from, the stationary hearer. If u is zero,

$$\lambda = \frac{v}{n}, \text{ and } n = \frac{v}{\lambda}.$$

If the sounding object is approaching the hearer the resulting wave-length λ_1 and frequency n_1 clearly are given by the relations

$$\lambda_1 = \frac{v-u}{n} = \frac{v}{n_1},$$

and

$$n_1 = \frac{nv}{v-u}.$$

Similarly, if the sounding object is receding from the observer,

$$\lambda_2 = \frac{v+u}{n} = \frac{v}{n_2},$$

and

$$n_2 = \frac{nv}{v+u}$$

Hence

$$n : n_1 : n_2 = 1 : \frac{v}{v-u} : \frac{v}{v+u}.$$

That is, the pitch is highest when the sounding object is approaching, and lowest when it is receding.

If, then, the sounding body were on a train, say, making 47 miles per hour, the pitch, as perceived by a person at rest near the

track, would drop approximately from G (approaching) to F (receding) on the musical scale.

If, however, the hearer is moving with the velocity w and the sounding object is at rest, on approaching the body

$$n_1 = \frac{v+w}{\lambda},$$

and on leaving it,

$$n_2 = \frac{v-w}{\lambda}.$$

Hence, in this case

$$n : n_1 : n_2 = v : v+w : v-w$$

If both object and hearer are in motion the expressions for the pitch ratios are only a little more complex—no new principle is involved.

Sound Perception in the Inverse Order of Sound Production.—Another interesting consequence of the moderate velocity of sound propagation is the occasional perception of sounds in the inverse order of their production. This is especially noticeable in the case of high velocity cannon shells passing close by or over one from a considerable distance. Such projectiles often have double the velocity of sound. Hence the first thing heard is the whine of the shell, then its explosion, perhaps, and last of all the firing of the cannon; or, the explosion may be heard last, if far to the rear. All this is obvious when it is recalled that the shell is continuously producing sound far in advance of the initial wave-front from the cannon.

It is also interesting to note that when the source moves faster than sound, as do cannon shells, the wave-front envelop is a cone whose vertex is at the source, and whose angular opening α is given by the equation

$$\sin \frac{\alpha}{2} = v / s,$$

in which v and s are the velocities of sound and of the shell, respectively.

Velocity of Intense Sounds.—Whenever a sound is produced by a violent explosion, such as by the firing of a cannon, the blast itself drives through the air and gives to the sound a velocity which at first, that is, so long as X in the general velocity equation is real and positive, is in excess of that which applies when X is zero.

This excess velocity, however, occurs only relatively near the

source of the sound, and rapidly decreases with distance from that source. That is, the external force X is soon reduced to a negligible quantity, after which the velocity becomes constant with the value appropriate to $X = 0$.

Sound Reflection.

Reflection by a Rigid Surface.—As above explained, all sounds in the atmosphere are propagated in the form of successive compressions and rarefactions. If, therefore, these air-waves should impinge normally on a wall of stone, or other dense material, it is obvious that they could not pass on unaltered. If the wall is absolutely unyielding, a condition solid and liquid boundaries more or less approach with respect to slight variations of atmospheric pressure, evidently the adjacent molecules cannot oscillate in the line of propagation. The pressure actions then of the wall on the atmosphere are precisely the same as they would be if it and not the air were vibrating with the given period and amplitude. Hence sound-waves incident on an absolutely rigid wall are wholly reflected, and in such a manner that the surface of this wall is a place of minimum (zero) motion—the incident and the reflected wave having always exactly the same phase at the boundary.

Reflection at a Free Surface.—The effect on sound of a medium of the opposite rigidity extreme, that is, infinitely yielding, such as empty space, is also interesting, though not realizable in the case of the atmosphere. Here the incident compression tends to drive the boundary molecules of the first medium away; if, however, they are restrained from flying off, as is the free end of a vibrating rope, say, or the surface of a liquid, this restraint must be of the nature of a tension. In this way the flux of incident energy is reversed in direction—the waves are reflected. Furthermore, since change of pressure is impossible at a free boundary, the incident waves always have exactly opposite phases at the boundary reflecting surface.

Reflection at an Air Interface.—Let the boundary be between masses of air at the same pressure, but of unequal density owing to difference in temperature, or humidity, or both. This case is of especial importance since it includes the problems of internal atmospheric reflections, and of reflections from fogs and clouds.

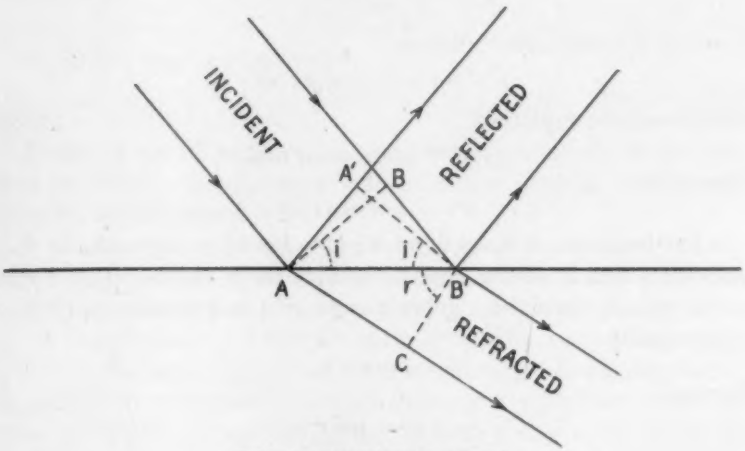
Here, too, as in so many other acoustical problems, the most general treatment is given in Lord Rayleigh's "Theory of Sound."

But the physical significance of each step in this elegant analysis is, perhaps, not easy to visualise. Hence a more obvious course of reasoning will be followed, based on Fresnel's theory of the reflection of polarized light.[5]

If none of the energy of the incident sound waves is transformed into heat at the boundary (and there is no evidence of any such transformation) clearly all of it must be contained jointly in the reflected and the refracted waves.

The laws of the reflection and refraction of sound in still media

FIG. 2.



Reflection and refraction of sound.

are the same as those of light. They are given below, but assumed here for convenience.

Let, then, the incident, reflected, and refracted waves be as indicated in Fig. 2; let their amplitudes be a, b, and c, respectively; let the velocity in the first medium be v, and in the second v'; and let the densities of these media be ρ and ρ', respectively. Then, since the energy in the incident wave is divided between the reflected and the refracted waves without loss, and in each case is proportional to the volume affected, obviously, and to the square of the respective amplitudes as immediately explained below,

$$v\rho a^2 = v\rho b^2 + v'\rho' c^2 \cos r/\cos i$$

in which i is the angle of incidence and r the angle of refraction.

[5] Fresnel, "Oeuvres," i, pp. 649–653; also Preston, "Theory of Light."

To show, as just assumed, that sound energy is proportional to the square of the amplitude, let f be the restorative, or elastic, force; a the amplitude (extreme displacement of a particle from its position of rest) and w the work of displacement. Now, f is proportional to the compression, that is, to the displacement, x, say. Hence,

$$dw = f\,dx$$

but

$$f = kx,$$

k being a constant, and

$$w = k\int_0^a x\,dx = \frac{k}{2}a^2.$$

Now, $v/v' = \sin i/\sin r$; hence,

$$\rho\,(a^2 - b^2)\sin 2i = \rho' c^2 \sin 2r.$$

Also, as above explained

$$(\rho'/\rho)^{1/2} = v/v' = \sin i/\sin r.$$

Therefore

$$a^2 - b^2 = c^2 \tan i \cot r.$$

Furthermore, if there is no slipping between the media at their interface, and it seems impossible that there can be to an appreciable extent, then the algebraic sum of a and b must equal c, or algebraically

$$a + b = c.$$

Hence,

$$a - b = c \tan i \cot r$$

$$b = -a\,\frac{\sin(i-r)}{\sin(i+r)} = -a\,\frac{\left\{(\rho'/\rho)^{1/2} - \cos i/\cos r\right\}}{(\rho'/\rho)^{1/2} + \cos i/\cos r}$$

and

$$c = \frac{2a\cos i\sin r}{\sin(i+r)} = \frac{2a\cos i}{(\rho'/\rho)^{1/2}\cos r + \cos i}$$

If, then, sound waves in a clear atmosphere, say, should impinge normally on a fog bank, or a cloud, in which the density of the air at the same pressure is one per cent. less—a possible ratio owing to differences in temperature and humidity—the energies in the incident, reflected, and transmitted (refracted) waves will have to each other the following ratios, approximately:

$$v\rho a^2 : v\rho b^2 : v'\rho' c^2 = 160{,}000 : 1 : 159{,}999.$$

In making this calculation the small correction due to differences between the specific heats of the two masses was neglected.

If the angle of incidence is not zero as just assumed, but of considerable size, the reflection obviously is greater, but still small for any angle up to nearly 90°. If, for instance, $i = 80°$ and $\rho'/\rho = 99/100$, as above assumed,

$$v_\rho a^2 : v_\rho b^2 = 100 : 1,$$

roughly. Clearly, then, reflection from fogs and clouds, or at any sharp boundary of sufficient size (greater than wave-length dimensions) between masses of air at the same pressure but of unequal density, varies from a very small value at normal incidence up to total reflection at

$$i = \sin^{-1} (\rho'/\rho)^{\frac{1}{2}}$$

If, as above, $\rho'/\rho = 99/100$,

$$i = 84° 15'$$

nearly.

Hence a small number of successive total reflections—not likely to occur, though conceivable—might greatly change the direction of the sound.

If the change in density is gradual through a distance of many wave-lengths—if the medium has no definite boundary—reflection is practically absent, as the equations show. For instance, there can be no reflection of sound from the gradually attenuating upper layers of the atmosphere, as demonstrated by Lord Rayleigh.[6] The energy is maintained through increase of amplitude with decrease of density, except as reduced, as it all finally is, by viscosity, to heat.

Laws of Sound Reflection.—By careful experiment it has been determined that sound is reflected according to exactly the same laws as those that apply to light, namely:

1. The normal at any point of the reflected surface and the directions of incidence and of reflection at the foot of this normal all lie in a common plane.

2. If the reflecting surface is flat and its every diameter large in comparison with the wave-length, the reflection is regular; that is, the angle of reflection (angle between the direction of reflection and the normal to the surface at the point of reflection) is equal to the angle of incidence.

3. Surfaces with less than wave-length diameters do not regularly reflect sound, but merely scatter or diffuse it.

[6] *Phil. Mag.*, 39, p. 173, 1890.

Echo.—It is well known that in the neighborhood of a flat, vertical wall of some size a loudly spoken word, or brief sentence, often is twice intelligibly heard; the first time as coming straight from the speaker, and the second as if coming from some invisible person in the direction of the wall. This latter sound is the familiar echo (nymph of the poets who pined away until only her voice was left) due to reflection by the wall of the incident condensations and rarefactions in the atmosphere. Parallel walls facing each other, the walls of a canyon, for instance, and separated a few hundred feet, may so reflect and re-reflect the same sound as to cause it to be distinctly heard again and again, through a long fading series. If the reflecting wall is quite irregular, or, especially, if there are walls of various shapes and distances on all sides, the multiplicity of echoes becomes jumbled into a continuous, unintelligible reverberation, a phenomenon most pronounced, perhaps, in certain caves—and auditoriums.

There are of course many natural phenomena due to echo, or sound reflection. Some of the more interesting are: (*a*) the discrete single echo; (*b*) the discrete multiple echo; (*c*) the overlapping multiple echo—reverberation; (*d*) the diffuse echo; due to scattering of the sound by many relatively small objects; (*e*) the harmonic echo; due to the greater scattering of an overtone than of the fundamental by small objects—the scattering of sound, like that of light, being inversely proportional to the wave-length; (*f*) the musical echo; due to reflection from, or scattering by, a series of objects, such as palings or stairsteps, spaced at uniformly increasing distances from the source.

Obviously a single sound impulse such as the crack of a whip, a clap of the hand, and the like, in front of a flight of steps, or just beyond and a little to one side of a row of palings, will be scattered by the successive steps, or palings, respectively, in a series of regularly spaced similar pulses. Hence the "echo" thus produced of any sound pulse is a musical note, whose pitch depends not on the parent sound, but on the spacing of the palings or width of stair treads, as the case may be, and position of the observer.

If s is the spacing of the pickets, or distance from centre of one to the centre of the next, along the path of propagation of the incident sound; and if the origin of the parent sound impulse is nearly in line with the row of pickets, then the distance between the

sound impulses, or wave-length l, due to any few successive pickets, is given by the equation

$$l = s\,(1 + \cos\theta)$$

in which θ is the angle, at the pickets in question, between the origin and observer.

An observer therefore at the source, which, as above explained, is beyond the row of pickets and a little to one side, hears a distinctly musical echo of each sharp sound pulse; since at his place the value of cos θ is very nearly the same, unity, for all the pickets, and hence the pitch substantially constant. If, however, the observer is off from the middle of a long straight row of palings, and the source of the impulse is located as before, cos θ will vary from nearly -1 to nearly $+1$, and the echo heard sweep down from the inaudible through a considerable range of the shriller notes.

Sound Refraction.

Sound Refraction in Still Air of Uniform Temperature.—The direction of propagation of sound is abruptly changed whenever it passes obliquely from one to another mass of air at the same pressure but of different density. This is owing to the fact that the velocity depends on the density, as above explained.

If both masses are quiet and equally humid, the velocity of propagation is inversely proportional to the square root of the density. If then i is the angle of incidence in the air whose density is ρ and r the angle of refraction in the air whose density is ρ', the change in direction, as indicated in Fig. 2, is the difference between i and the corresponding value of r as given by the equation

$$\sin r = \sin i\,(\rho/\rho')^{\frac{1}{2}}$$

The laws of refraction in this case are identical with those of light, namely:

1. The normal, at any point of the refracting surface and the directions of incidence and of refraction at the foot of this normal all lie in a common plane.

2. The sine of the angle of refraction (angle between the direction of refraction and the normal to the surface at the point of refraction) is to the sine of the angle of incidence as the velocity in the refracting medium is to the velocity in the incident medium; or inversely as the square roots of the densities of the re-

spective media, or directly as the square roots of their absolute temperatures.

Spread of Sound.—Since the velocity of sound in an atmosphere of homogeneous composition is, as previously explained, directly proportional to the square root of the absolute temperature, and since the atmosphere, when at rest, frequently is horizontally stratified with respect to temperature, it follows that sound cannot always spread in precisely the same manner.

Special cases are interesting:

(*a*) Temperature uniform, air quiet and of constant composition. Under these conditions, which, however, never exist, sound would spread uniformly in every direction.

(*b*) Temperature decreasing uniformly with elevation, air quiet and of constant composition. These conditions often are approximately fulfilled through a considerable depth of the atmosphere. They evidently give an oblate ellipsoidal sound shell, with the shorter axis, axis of rotation, vertical. If the origin is on a horizontal surface, the wave front tends to incline upward, owing to the greater velocity in the lowest and warmest air, and hence, the sound to become faint, or even lost, at points on this surface.

(*c*) Temperature increasing upwards (temperature inversion), air quiet and of constant composition—conditions that obtain on a typical frost night.

Let the surface be an indefinite plane, such as the surface of a large frozen lake, and let the temperature be 0° C. at the surface and increase rapidly with elevation to a maximum of 6° C. at, say, 20 meters elevation, and let a sound be produced near the surface.

The velocity of sound, since it varies as the square root of the absolute temperature, will therefore be about 1/100 greater at the top of this inversion layer (layer through which temperature increases with elevation) than at the surface. Hence total reflection will occur for all sound leaving the source between the angles i and $\frac{\pi}{2}$ to the vertical; i being determined by the equation

$$\sin i = \frac{100}{101} \sin 90°,$$

from which $i = 82°$, about.

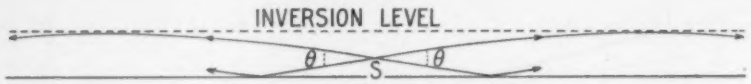
Hence the whole volume of sound leaving the source S, Fig. 3, within a horizontal toroidal wedge of angle θ (16° in this case) is confined, by refraction above and reflection below, to the surface

layer of 20 metres depth. At times this inversion layer is much shallower, but whatever its thickness it is, acoustically, a "speaking disk" in which the intensity of sound is inversely proportional, roughly, to the first power only of the distance. This explains why sounds often carry surprisingly far on still, clear nights.

As a further illustration of this phenomenon let the temperature inversion occur over a river whose banks are free of trees and steep, or canyon-like. Here not only the vertically spreading sound is constrained to a shallow layer, as above explained, but also the horizontally spreading portion is roughly confined to the course of the river by reflection from the banks. That is, the river is one wall of a gigantic "speaking tube" through which sounds occasionally are heard at amazing distances.

(*d*) Temperature rapidly decreasing upward for a few metres, air quiet and of constant composition. Under these un-

FIG. 3.



Sound confined to an inversion layer.

stable conditions sounds travel appreciably faster near the surface than at some distance above it. Hence, sounds originating within or but little above this relatively high temperature surface layer may pass entirely over one's head, even as close as 100 metres to the source, owing to the greater velocities of the lower portions of the sound waves, in proportion to the square roots of the absolute temperatures, and the consequent upward inclination and propagation of these portions of the wave fronts.

Under the given conditions in the lower air and with an approximately constant temperature through the next layer above, a sound front may be shaped substantially as shown at *ABC*, Fig. 4, and if so it must later develop into the front *A'B'C'*. Owing to refraction *CC'* will not be quite straight, but may be so drawn to represent the general results.

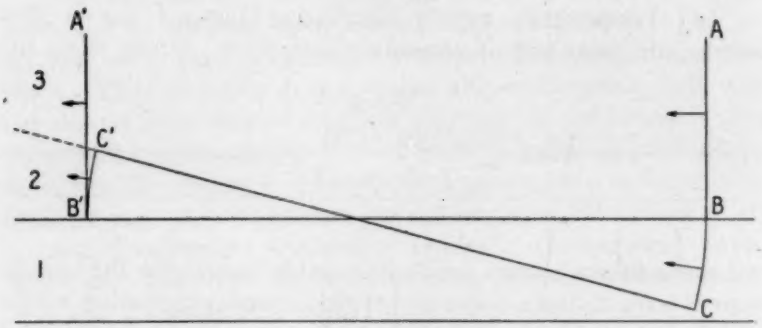
Clearly, then, under the given conditions a person in region 1 will hear only a faint sound, if any at all; at 2 he will hear two identical sounds, probably more or less out of phase, one from the direction of the actual source as given by the undistorted wave front *A'B'*, and the other apparently from some point more or

less below the actual source, as indicated by the front $B'C'$. At 3 only one sound is heard, namely, the undisturbed original, and, of course, in its true direction.

The phenomena here described are identical with those of the inferior optical mirage, and are due to the same meteorological conditions. They constitute, therefore, the *inferior acoustical mirage*. Indeed a series of sounding objects arranged vertically might, in position 2, if one were equipped with a suitable sound-pointer, be heard both right side up and upside down.

(*e*) Temperature uniform throughout a shallow layer, then increasing with elevation over several meters to a uniform higher

FIG. 4.



Inferior acoustical mirage.

temperature above, air quiet and of constant composition—conditions identical with those that give the superior optical mirage.

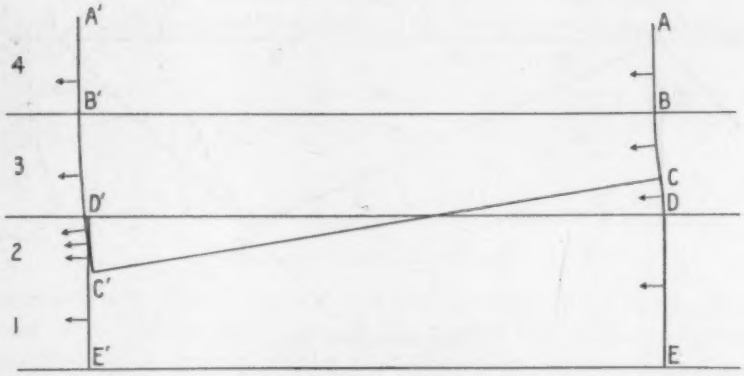
The necessary acoustical consequences of this assumed, and sometimes actual, temperature distribution, may be easily inferred by the aid of Fig. 5. After the sound whose origin is at only a moderate elevation, has traveled for some distance its wave fronts have some such shape as that indicated by *ABCDE*, in the figure, owing to the relation of sound velocity to temperature, as explained above. Farther on this front obviously transforms into *A'B'C'D'E'*, of the figure, from which it appears that: In position 1 only a single sound is heard, and in the direction of the source; in position 2, three identical sounds are possible, one in the correct direction, another apparently from a slightly higher point, and inverted if, as explained under *d*, that be possible, and a third, not inverted, apparently from a still higher point; in position

3, a single sound, apparently from a point distinctly above the true source and, finally, in position 4, also a single sound and again, as in position 1, in the direction of the source.

Since these phenomena are closely analogous to those of the superior optical mirage, and have identical causes, it is suggested that they be called the *superior acoustical mirage.*

Sound Refraction by Straightaway Winds.—Everyone knows, of course, that, in general, winds do not prevent sounds from being heard. Obviously, however, the vibrating portions of the air are carried along with the wind, or, rather, are a portion of it. Clearly, then, the effect of a known wind on the path of a sound

FIG. 5.



Superior acoustical mirage.

ray can be computed with all desired accuracy. Thus, following Barton [7] substantially:

Let *AB*, Fig. 6, be the boundary between two horizontal layers of air; let the wind velocity in the lower layer be u_1, and that of the upper u_2, both in the same direction, and $u_2 > u_1$; let θ_1 and θ_2 be the inclinations of the wave fronts to the horizontal in the lower and upper layers, respectively; let ϕ_1 and ϕ_2 be the corresponding angles between the sound paths in the two layers and the vertical, and let the velocity v of sound in still air be independent of altitude—true, on the average, to about one part in a hundred between bottom and top of the lowest kilometer, and correspondingly nearer true in this region for less depths.

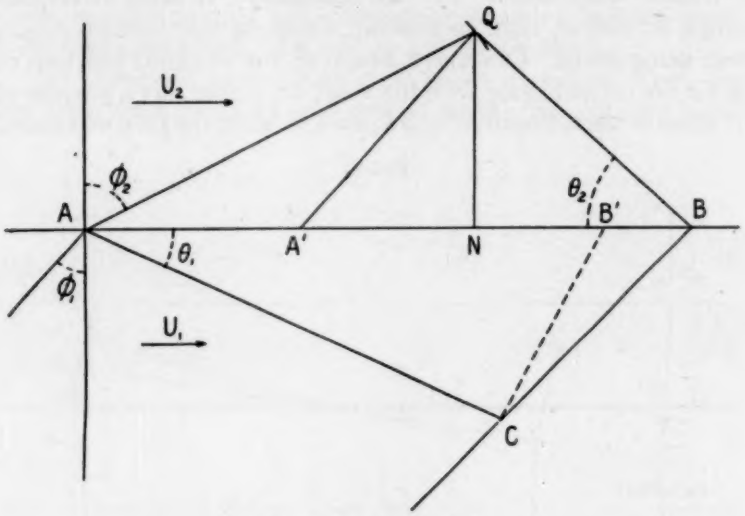
Draw *CB'* at right angles to the wave front *AC*, or along a

[7] "Text-book of Sound," Macmillan, 1908, pp. 99–106.

sound path for still air of uniform temperature and composition, and let $B'B$ have such value that $B'B/CB' = u_1/v$. Then CB is the actual sound path in the lower layer.

To find the wave front in the upper layer resulting from the front AC in the lower, draw $AA' = B'Bu_2/u_1$, describe about A_1 a

FIG. 6.



Sound refraction by wind.

circle whose radius $A'Q = CB'$, and draw BQ tangent to this circle. This tangent BQ is the wave front desired. From the figure

$$\text{cosec } Q\,B\,A' = \frac{BA'}{A'Q} = \frac{B'A - AA' + B'B}{CB'}.$$

Hence,

$$\text{cosec } \theta_2 = \text{cosec } \theta_1 - \frac{u_2 - u_1}{v},$$

and, for any layer whatever,

$$\text{cosec } \theta = \text{cosec } \theta_1 - \frac{u - u_1}{v},$$

or

$$v/\sin\theta + u = v/\sin\theta_1 + u_1,$$

in which θ and u apply to the layer in question.

Clearly, then, since the limiting value of the cosecant of an angle is unity, any pair of values of θ_1 and $u - u_1$, which makes

cosec θ in the above equation less than unity provides a case of total reflection.

Obviously, the actual path of a sound ray can be traced through the various layers when their speeds and directions of motion, temperatures, and other acoustical factors, are all given. Thus, from the figure, in which QN is perpendicular to AB, it is evident that

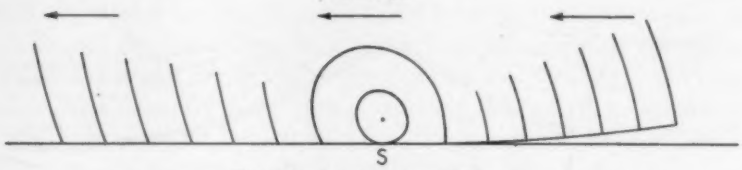
$$\frac{AN}{QN} = \frac{A'N}{QN} + \frac{AA'}{QA' \cos \theta_2},$$

and, therefore, that in every layer

$$\tan \varphi = \tan \theta + \frac{u}{v} \sec \theta.$$

If u increases continuously and uniformly with elevation, and if the temperature and composition of the air are the same along

FIG. 7.



Distortion by wind of sound fronts.

the sound path, then it is possible to find an equation for the path, at least in the vertical plane through the origin. But as the conditions specified never strictly obtain, the solution is scarcely more than an abstract mathematical exercise, and therefore will not be given here.

From the above discussion of the effect of the bodily movement of air on the velocity and direction of travel of sound, it is obvious that its leeward and windward distributions may be radically different.

Let the centre of the distorted circle above S, Fig. 7, be the place of origin of a sound, and let the wind be blowing from right to left, as indicated, and increasing with elevation. Obviously, the velocity of the sound, and the consequent distances between the successive compressions and rarefactions will be greatest on the leeward side and least to the windward. The pitch, however, if source and observer are both stationary, will be the same. Furthermore, since the propagation is normal to the wave fronts, the sound is lifted to the windward as indicated in the figure, and thus be-

comes faint, if not quite inaudible, to one on or near the surface in that direction. On the other hand, it is driven down to leeward, in which direction it consequently is heard much farther and louder. All of which are matters of great importance in fog and other sound signaling. Indeed it is even possible for the lifted sound to windward to strike a shore cliff, or other object, and be reflected back in such manner that the echo alone is heard, and the friendly, warning signal thereby transformed into a fiendish lure to danger.

From the figure it is also evident that the sounds are much farther and better heard to the windward from elevated sources than from those near the surface—hence one of the great advantages in having bells in high steeples rather than near the ground. Likewise, sounds to windward, especially if originating

FIG. 8.

Sound crossing a mountain to leeward.

near the surface, often are best heard at elevated points; better in the "crow's nest," for instance, than on the deck.

Another interesting phenomenon in this connection is the carrying of sounds from the windward to the leeward side of a mountain where they sometimes are so distinctly heard as to appear but a little way off. The wind, increasing in speed with distance from the surface, flows parallel, roughly, to the mountain sides—up one side and down the other. Hence the forward portion of a wave front tends more and more towards the vertical as it climbs the windward side of the mountain, crosses the ridge upright (if the wind is suitable) and then focuses onto the leeward valley beyond, all as diagrammatically illustrated in Fig. 8, in which *S* is the source of the sound and *F* its diffuse leeward focus, determined by the wind currents, as indicated in the figure by the progressive positions of the wave front.

The acoustical effects of oppositely directed winds in adjacent layers are worth considering, because such opposing winds frequently occur, for instance, when, in middle latitudes, the surface

wind is from the east; in places of strong land and sea breezes; and in all trade wind regions.

The general effect in question is quite obvious from Fig. 7. That is, a sound made near the surface, by the firing of a large cannon, say, is first lifted on the windward side as indicated, and later, on getting into the oppositely directed upper current, tipped forward and downward, as readily conceived, though not indicated in the figure. In this way exceptionally loud sounds occasionally are heard a hundred miles or more from the source, and over extensive areas beyond a broad zone of silence.

Locating by Sound.

Sound Pointing.—It is well known that a very small difference in the phase of a sound as it enters the two ears generally is quite perceptible.[8] If then one could actually, or virtually by some artificial aid, stretch his ears far apart, and listen in at widely separated portions of the wave front he obviously could determine the direction of the sound arrival with great precision. And this has been done[9] by the aid of long, gently tapering, hollow cones, mounted some distance apart with their axes parallel, quickly adjustable in direction, and supplied, at their smaller ends, with aural tubes.

On correcting for refraction, due essentially to wind and differences in temperature (often impossible to do very accurately), the direction of the source, or, at least, its direction when the received sound was emitted, is determined.

Sound Ranging.—Not only is it possible to determine the direction of the source of a sound, but, by the aid of three listening stations, its exact location as well. In this way the positions of many enemy cannon were located during the world war.[10] The details of sound ranging, as the exact location of an object by sound is called, are numerous and their variations many. Nevertheless, the underlying principles are very simple.

Let *A, B, C,* Fig. 9, be three listening stations and *O* the place of origin, to be determined, of the sound pulse—place of the firing cannon, say. Let *v* be the velocity of sound in still air appropriate to the current temperature and humidity. Corrections can easily be made for any observed wind, but for simplicity it will be assumed

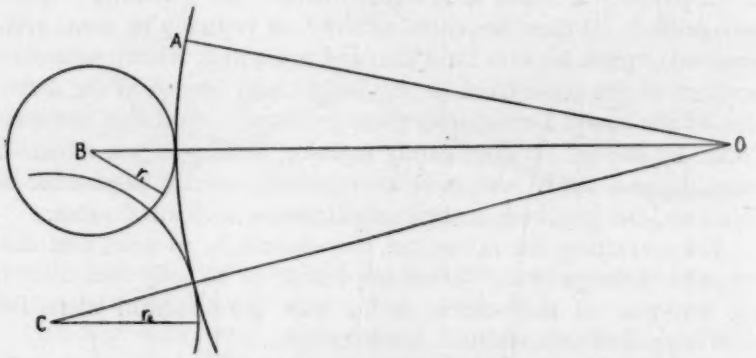
[8] Stewart, *Phys. Rev.*, 15, p. 432, 1920.
[9] Stewart, *Phys. Rev.*, 14, p. 166, 1919.
[10] Trowbridge, JOUR. FRANKLIN INST., 189, p. 133, 1920.

that there is no wind, and hence no wind corrections. Let the sound pulse originating at O, be received at A, B, and C at the times t_1, t_2, and t_3, respectively.

Then, at the time t_1 the pulse is at A, and distant r_1, or $(t_2 - t_1)v$, from B, and r_2 or $(t_3 - t_1)v$ from C. Hence, O is the centre of that circle whose circumference passes through A and is tangent to a circle of radius r_1 about B and also to another circle of radius r_2 about C.

Another method of locating O is to note that it is on the loci of three several points, the difference of the distances of one of which from A and B is r_1, a constant; of another from A and C is r_2, a constant; and of the third from B and C is $r_2 - r_1$, likewise

FIG. 9.



Sound ranging, or locating sound source.

a constant. That is, it is at the intersection of any two, and hence all three, of the hyperbolas whose foci are A, B; A, C; and B, C, respectively, conditioned by $OB - OA = r_1$; $OC - OA = r_2$; and $OC - OB = r_2 - r_1$, respectively.

Dissipation of Sound.—In an absolutely quiet and homogeneous medium the intensity of sound must vary inversely as the square of the distance from the source, except in so far as the mechanical energy of the waves is slowly dissipated into heat. In the ordinary atmosphere, however, at least near the surface, the intensity of sound decreases far more rapidly.[11] A portion of the excess in the rate of decrease of the intensity over that required by the inverse square law is due, no doubt, to internal reflections

[11] Stewart, *Phys. Rev.*, 14, p. 376, 1919.

and refractions incident to temperature irregularities. However, the dissipation of sound generally is more pronounced the stronger the wind. Hence, since winds smooth out horizontal temperature irregularities and establish an approximately adiabatic cooling with altitude (1° C. per 103 metres) it follows that, at least when there is considerable wind, some other factor than reflection and refraction of the type just mentioned must be effective in dissipating sound. This factor appears to be the ordinary turbulence, or eddy motions, of the lower air.

Since eddy motion is very irregular, both as to speed and direction, and since the velocity of only a moderate wind is several per cent. of that of sound (22 miles per hour equals about three per cent. of the velocity of sound) it follows that a sound front is greatly distorted on passing through such gusty winds as are common near the surface of the earth. These distortions obviously alter the direction of propagation—normal to the wave front—and on the whole increase the dispersion of the sound and rate of its enfeeblement.

To visualize the effect of eddies on sound a little differently, let an instantaneous distribution of atmospheric compressions and rarefactions, constituting a train of sound waves, be fixed in position except as acted on by mass movements of the air. Such inequalities would quickly be so intermingled by any moderately strong and turbulent wind as to practically obliterate the sound waves, and this same obliterative process is quite as operative, presumably, on travelling, as it would be on stationary waves. The time actually available for such operation is, of course, very brief, but it is sufficiently long, apparently, to permit a great reduction of the sound intensity.

Sounds to and from Elevated Points.—Balloonists, mountain climbers, and others, who have visited quiet places of considerable altitude, have reported two interesting sound observations:

(*a*) The balloonist, for instance, tells us that the higher-pitched sounds on the surface of the earth are heard to a greater altitude than lower ones of equal initial loudness. A chorus of spring frogs (*hylas*), for example, or the excited cackling of a flock of chickens, is heard after the human voice of at least equal loudness has faded away. This is in spite of the fact that the sounds of shorter wave-length are more rapidly dissipated by

atmospheric irregularities than are those of longer wave-length, and due to the greater sensitivity, within certain limits, of the ear to the higher-pitched notes [12]–to our keener perception here, as also in the case of earthquake shocks, of acceleration than of amplitude.

(*b*) The balloonist may hear and understand persons on the ground while they cannot hear and understand him. This fact is so striking that it has repeatedly evoked wonderment and comments. Its explanation, however, is not, perhaps, immediately obvious. Probably several factors contribute to the final result, among them:

1. Since the density of the atmosphere is less at the level of the balloon than on the ground, it follows that the voice of the balloonist will be correspondingly weaker (carry less energy) than that of a person on the surface. At an altitude of half a mile, probably about the limit at which vocal communication is possible, the density of the atmosphere is still nine-tenths, roughly, that near the ground. Hence, the density factor, while in the right direction, is not sufficient to account for the commonly observed differences in audibility.

2. The pilot hears both the direct and the reflected portions of the voice below him (whether reflected by the horizontal surface or by objects on it) in substantially the same direction, while the ground observer hears the balloonist's direct voice from overhead, its chief reflection from below, and minor reflections more or less from all around horizontally. Just what the resultant will be in each case is not obvious, but it would seem that with respect to this factor also the balloonist has the better listening position.

3. The balloonist, even when up only half a kilometre, is in a region prevailingly of utter silence, where any occasional sound is most easily perceived. On the other hand, his surface interlocutor is immersed in a flood of sound, where the limit of audibility is soon reached. That this difference in noise environment is an important factor in the cause of the phenomenon under consideration is evident from the fact that the balloonist often can hear the earth echo of his own voice when he is unable to arrest the attention of persons below him.

[12] Sabine, *Contributions, Phys. Lab. Harvard Univ.*, No. 8, 1919. Stewart, *Phys. Rev.*, 14, p. 376, 1914.

CHAPTER II.

SOUNDS OF METEOROLOGICAL ORIGIN.

Creaking of the Snow.

PROBABLY all, or nearly all, who have experienced a cold winter are familiar with the cheery cry of the snow as it is pressed against a hard surface by the steel tire of a wagon, for instance, or even onto a pavement by the heels of one's boots.

When the temperature is just a little below the freezing point, the snow, then in fine condition for snowballing, does not creak, and the track of the wheel is marked by a strip of more or less compact ice. On the other hand, when it is so cold that the snow will not ball, its voice is loud, and the track left by the wheel is now marked, not by a strip of compact ice, as before, but by a trail of crushed and powdered crystals.

In the first case, that is, when the temperature is only a little below freezing, the snow crystals obviously melt, to a greater or less extent, as a result of the pressure to which they are subjected, and undergo regelation immediately the pressure is removed. The yielding is gentle and progressive through melting and flowing, and not of that abrupt nature essential to the production of sound.

In the second case, however, or when the snow is too cold to melt under the pressure applied, its yieldings and readjustments are abrupt and jerky incident to the crushing of the crystals and their slippage in a dry condition over each other. It is these abrupt yieldings, these sudden breaks and slips of its dry crystals, that produce the familiar cold-weather creak and cry of the snow.

Thunder.

Cause.—Thunder, one of the most familiar and certainly the most impressive of all meteorological sounds, has been "explained" in many ridiculous ways, but generally, perhaps, just accepted. Any careful observation, however, will soon show that thunder is associated with lightning, and that the lightning flash always precedes the thunder. Clearly, then, thunder is somehow caused by lightning.

Now, it is known that sudden and intense heating, and molecular dissociation occur along the path of a lightning discharge. Hence a corresponding abrupt expansion, simulating a violent explosion, also occurs along this path; and this expansion in turn produces

a compression wave in the surrounding atmosphere that travels outward exactly as would any other sound wave.

Musical Thunder.—It occasionally happens, when one is near the path of a lightning flash, that the thunder heard begins with a musical note. This is due to the fact that some lightning discharges—the flickering type—consist of a series of rapid flashes that occasionally are nearly enough regular, and of such frequency, as to produce a quasi-musical note.

Duration.—The long continuation of thunder is due, chiefly, to the great difference in the distances of the nearest and farthest points of the lightning path from the observer. If this difference is five miles, as it occasionally is, the duration of the thunder, owing to this cause alone, is roughly 24 seconds.

The duration of thunder is also prolonged by reflection. Occasionally the echo prolongation is very pronounced, but it is everywhere variable and uncertain.

Rumbling.—The great variations in the intensity of thunder that constitute its characteristic rumbling are due:

(*a*) To crookedness of path. The thunder starts from all parts of the discharge path simultaneously, or practically so, and thus the observer hears simultaneously the thunder from the whole of any portion of the path that happens to be at a constant distance from him. Now, as the path usually is very crooked, it generally happens that many portions of it are at one or another nearly constant distance from any given point. Hence, almost every peal of thunder is of irregular intensity, and as no two lightning paths are alike so also each peal of thunder differs from every other.

(*b*) To the sequence of discharges. Obviously, when a number of discharges follow each other in rapid succession—when the lightning is flickering—there is likely to be more or less interference between the several sound pulses resulting now in partial neutralization and again in reinforcement, the whole merging into an irregular rumble.

(*c*) To reflection. Reflection by mountains, hills and other objects may occasionally be effective in prolonging the noise of thunder and accentuating its rumble. However, mountains and hills are not nearly so essential to the rumble of thunder as occasionally they are said to be, for the rumble of the thunder, whether in the valley, on the plain or on the peak, is substantially the same.

Distance Heard.—Thunder seldom is heard more than 15 miles. This is much less than the distance to which cannon are sometimes heard. The circumstances in the two cases, however, are radically different. Thus, the sound energy from the cannon is relatively concentrated since it all starts from a single point and spreads out in a hemispherical shell, whereas, that of thunder starts, not from a single point, but from a crooked line often miles long. Furthermore, cannon often are fired when the surface air in which the firing occurs, is very still and otherwise in the best state for long transmissions of sound. Thunder, on the other hand, seldom occurs except when the winds are turbulent and the general conditions very adverse to sound propagation. Finally, the density of the air is greater at the cannon than along the lightning path, and hence its sound energy per unit volume, other things being equal, also correspondingly greater in the former than in the latter case.

Brontides.

From time immemorial low, rumbling, thunder-like noises (brontides, *mistpoeffers,* "Barisal guns," etc.,) of short duration, and that certainly are not thunder, for they often occur when the sky is clear, have been heard in many parts of the world, both singly and in irregular series. They appear to come from a distance, but of uncertain direction, and are most frequent in actively seismic regions.

Apparently, then, the true brontides (many other sounds have often been mistakenly reported as brontides) are only the rumblings of earthquakes too feeble for registration or other than aural detection. And this inference is strengthened, if not indeed confirmed, by the fact that earthquake adjustments have been known to occur in a long irregular series of shocks that became feebler and feebler until only the characteristic low rumbles (then properly called brontides) remained, as presumable evidence of their passage.

Howling of the Wind.

One of the compensations for being snowbound on a windy day is the pleasure of listening to the well-known howling of the wind as it sweeps by the chimneys and over the gables, and wondering where it gets its many voices, or, indeed, any voice at all. Nor is the wonderment yet over, for the problem of the howling

of the wind has never been completely solved, at least not in the fullness of all the differential equations that tell the whole story. This much, however, is known: the howling, like the other æolian sounds discussed below, is due to eddy motions in the atmosphere immediately beyond the obstructing object. There is no resonance or other organ-pipe action, for the change from one pitch to another is not by jumps, as it is in all pipes, but gradual, through every intermediate value, in response to the varying wind velocity.

Let the direction of the wind make an appreciable angle with the roof and let the latter either project a little beyond the gable wall or, at least, come up flush with it. Under these conditions the wind will have its maximum velocity as it leaves the roof, and there in only a comparatively thin sheet. This sheet in turn, immediately it escapes the roof, drags along, through viscosity, some of the air just beneath it, and is itself slightly deflected in the direction of the consequent pull. In this way an abrupt change in the direction of flow is produced at the edge of the roof and hence an eddy will immediately start at that place. One effect of such an eddy, since it enters the current from relatively still air, is to slightly decrease the velocity of that current. It is quickly carried on, however, and the eddy-forming conditions thereby renewed. In this general manner, presumably, eddy after eddy is formed at the edge of the roof with such frequency and such approach to regularity as to produce a more or less musical note whose pitch increases with the wind velocity.

These sounds generally are much better heard indoors than out. This is largely, if not wholly, because one is there far less disturbed by the innumerable other outdoor noises, especially the continuous and annoying whisper of the wind right in one's ears—also an eddy effect.

Humming of Wires.

Few things, perhaps, have been more absurdly "explained" than has the well-known humming of telegraph and telephone wires, and that in spite of the fact that the correct explanation has long been at hand.

It was shown by Strouhal[13] that wind normal to a cylinder, such as a stretched wire, produces æolian tones even when the

[13] *Ann. d. Phys.*, 5, 216, 1878. See also Lord Rayleigh, *Phil. Mag.*, 29, p. 433, 1915.

cylinder itself takes no part in the vibration; that the pitch of the note thus produced, independent alike of the material, length, and tension of the wire, varies directly as the speed, u, of the wind and inversely as the diameter, d, of the obstructing rod; and that the number, n, of such vibrations per second is given, approximately, by the equation

$$n = .185\, u/d$$

the units being the centimetre and second.

Whenever the tone thus produced coincides with one of the proper tones (fundamental or a harmonic) of the wire, the wire itself, if suitably supported, then vigorously vibrates, normal to the direction of the wind, and thereby increases the loudness and also holds the pitch fixed over a considerable range of wind velocity. The sound in question, however, that is, the humming of telegraph and telephone wires, is not due to the elasticity of the wires (the pitch changes gradually with wind velocity and not from harmonic to harmonic), but to the instability of the vortex sheets their obstruction introduces into the air as it rushes by them. This obvious and, indeed, unavoidable deduction from Strouhal's experiments, just referred to, is abundantly confirmed by cinema photographs of water eddies, due to flow past a cylinder, made at the National Physical Laboratory. Vortex whirls developed at regular intervals, alternately to the right and left of the interfering cylinder, while the eddy mass vibrated from side to side in the same period, all as shown in Fig. 10, copied from Bairstow's "Applied Aerodynamics."

The complete mathematical analysis of these and similar vortices, giving the deduction of Strouhal's rules, and many others, would be both interesting and valuable, but it appears that this important problem has not yet been fully solved. Much progress, however, towards this solution, has been made by v. Kármán [14] and by v. Kármán and Rubach,[15] who have shown that evenly spaced vortices alternately on opposite sides is a stable arrangement, and the only one.

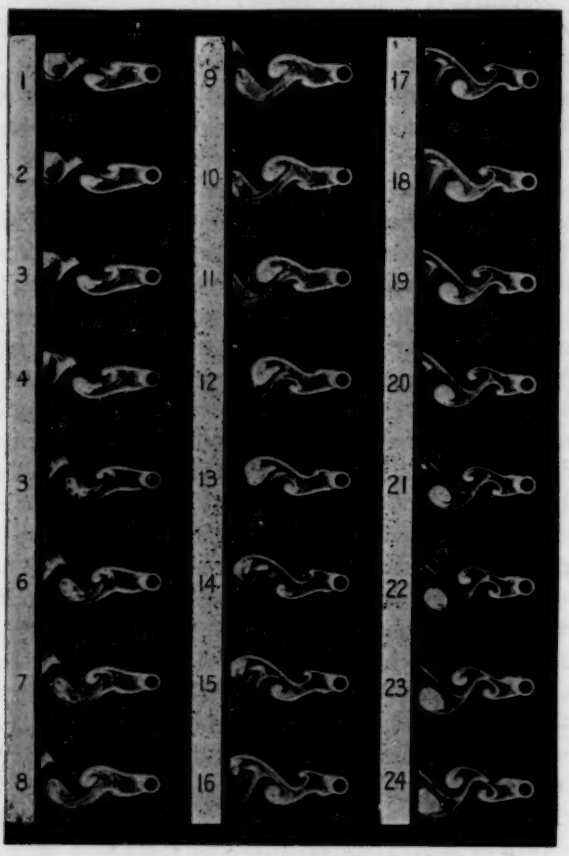
It is well known that the humming of telegraph and telephone wires is loudest when the wires are tightly stretched, as they generally are during cold weather. This appears to be because the

[14] *Göttingen Nachrichten*, 1912, *Heft*, 5, p. 547.

[15] *Phys. Zeit.*, 13, p. 49, 1912.

eddies thus produced in the wind vary the tension on the wire, and rapidly the more so the tighter, or straighter, it becomes. Now these variations of tension are transmitted to the posts which in turn act as sounding boards, analogous to the sounding board of a

FIG. 10.



Eddies behind cylinder (N. P. L.).

piano, and hence largely increase the volume of the sound, whatever its pitch.

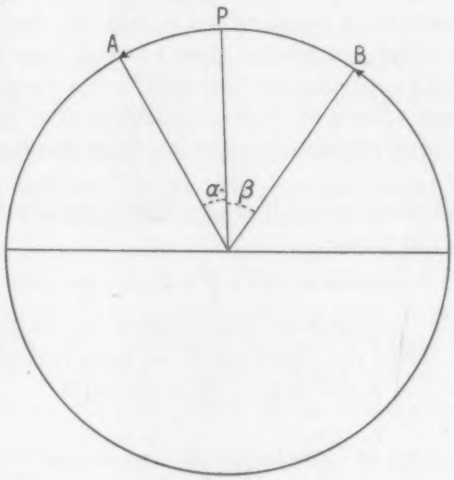
Whispering of Trees.

From the experiments of Strouhal, above referred to, it is evident that pine needles, bare twigs, and even the branches of

trees, must all produce æolian notes—that trees must have voices, even voices that are characteristic of the species. And they do. The muffled plaint of the oak at the wintry blast, for instance, has but little in common with the sibilant sigh of the pine. And the reason is obvious; the twigs and branches of the one, because relatively large and of many sizes, produce a multitude of low tones, while the innumerable fine needles of the other give a smaller range of high-pitched notes.

It may be granted that, as shown by experiment, each twig and

FIG. 11.



Phase circle.

other similar obstacle in the wind must produce an æolian note. But how, one must ask, do a multitude of such notes blend together—how are the pitch and loudness of the resultant related to the like properties of the constituents?

To solve this problem, let two sounds have the same amplitude, but differ slightly in period. Let them start together with maximum displacement, or at the top, *P*, of the phase circle, Fig. 11. Let the phase position of the quicker, after a few intervals, and at the instant when the resultant amplitude is at a maximum, be at *A* (having described the angle $2n\pi + \alpha$, n being a whole number) and that of the slower at *B* (having described the angle $2n\pi - \beta$); let s be the velocity along the circumference of the phase circle of

the slower, and $s+\delta s$ the corresponding velocity of the quicker. Then, since the combined amplitude is at a maximum

$$s \sin \beta = (s+\delta s) \sin \alpha, \text{ and } \beta > \alpha.$$

For the next maximum

$$s \sin (\beta+\delta\beta) = (s+\delta s) \sin (\alpha+\delta\alpha).$$

But

$$\delta\beta < \delta\alpha.$$

Furthermore, since the rate of increase of an angle is greater than that of its sine, the successive values of $\delta\beta$ will slowly increase so long as β and α are greater than 0, and less than $\pi/2$, and then decrease while they are greater than $\pi/2$ and less than π.

In short, the combination tone will have a varying pitch intermediate between those of its constituents. And this is also true of any number of constituent sounds—their resultant has a quasi-average pitch.

Analytically, assuming, for simplicity, equal amplitudes a and initially identical phase,

$$x = a \cos (2\pi m t - \epsilon) + a \cos (2\pi n t - \epsilon)$$

in which x is the resultant displacement at the time t after the initial count, when the phase epoch of each constituent vibration was ϵ, and m and n the respective frequencies.

Since

$$\cos (2\pi nt - \epsilon) = \cos\left\{2\pi mt - 2\pi (m-n)\, t - \epsilon\right\},$$

$$x = a \cos (2\pi mt - \epsilon) + a \cos\left\{2\pi mt - 2\pi (m-n)\, t - \epsilon\right\},$$

$$= r \cos (2\pi mt - \theta),$$

where

$$r^2 = 2a^2\left[1 + \cos\left\{2\pi (m-n)\, t\right\}\right]$$

and

$$\tan\theta = \frac{\sin\epsilon + \sin\left\{2\pi (m+n)\, t + \epsilon\right\}}{\cos\epsilon + \cos\left\{2\pi (m-n)\, t + \epsilon\right\}}$$

That is, the resultant is a quasi-harmonic in r and θ, each of which has the frequency $m-n$, while that of the combination is a varying intermediate between m and n.

A combination of two notes having different amplitudes and different initial phases gives equations substantially the same as the above, though, of course, slightly more complicated. Simi-

larly, a multitude of sounds merge into a quasi-note whose pitch is the approximate average of those of the many constituents. Hence the whisper of a tree, whatever its volume, has substantially the same pitch as that of its individual twigs or needles; just as the hum of a swarm of bees is pitched to that of the average bee, and the concert of a million mosquitoes is only the megaphoned whine of the type.

The final law of sound essential to the explanation of the whispering of trees, namely, the intensity of a blend in terms of that of its constituents, has been found by Lord Rayleigh [16] in substantially the following manner:

Let the number of individual sounds be n, all of unit amplitude and same pitch, but arbitrary phase—conditions that approach the æolian blend of a tree. Clearly, if all the individual sounds had the same phase, and unit amplitude, at any given point, their combined intensity at that point would be n^2. If, however, half had one phase, and half the exactly opposite phase, the intensity would be zero. Consider then the average intensity when all the vibrations are confined to two exactly opposite phases, + and −. Now, the chance that all the n vibrations will have the same phase, + say, is $(\frac{1}{2})^n$ and the expectation of intensity corresponding to this condition $(\frac{1}{2})^n n^2$. Similarly, when one of the vibrations has the negative phase and the $n-1$ others the positive phase, the expectation is $(\frac{1}{2})^n n(n-2)^2$; and the whole or actual expectation

$$\left(\frac{1}{2}\right)^n \left\{1.n^2 + n(n-2)^2 + \frac{n(n-1)}{1 \cdot 2}(n-4)^2 + \ldots\ldots\right\} \quad (A)$$

The sum of the $n+1$ terms of this series is n, as may be indicated by a few numerical substitutions; or proved, as Lord Rayleigh (*l. c.*) has shown, by expanding the expression

$$(e^x + e^{-x})^n$$

into the two equivalent series

$$2^n \left(1 + \frac{1}{2}x^2 + \ldots\right)^n \qquad \text{(Maclaurin)}$$

and

$$e^{nx} + ne^{(n-2)x} + \ldots\ldots \qquad \text{(Binomial)}$$

developing the exponentials into series of algebraic terms, and,

[16] "Encyclopædia Britannica," 9th edition, Wave Theory; Scientific Papers, iii, p. 52.

finally, assembling and equating the coefficients of x^2 in the two equivalent series, and solving for n. The value of n thus found is identical with the expression (A).

That is, on the average, the intensity of the resultant of n sounds of unit amplitude, but confined, in random numbers, to two opposite phases, is always n, whatever its numerical value.

If, instead of the numbers of sounds in either of two opposite phases being random, the phases are random, the result, as Rayleigh has shown, is the same.

It should be noted that n is only the mean intensity of a possible range from 0 to n^2, and not the continuous intensity. But when the changes are rapid the fluctuations from the mean are correspondingly inconspicuous.

From the above two laws, namely, (1) that the pitch of a composite note is the approximate average of those of its constituents, and (2) that the mean intensity is the sum of the individual intensities, it appears (a) that the pitch of the æolian whisper of a tree is essentially that of its average twig, or needle, if the tree be a pine, and (b) that though the note of the twig may be inaudible, even at close range, the tree may often be heard some distance away.

Murmuring of the Forest.

Just as the æolian whispers of the myriads of needles on a single pine tree, or of the numerous twigs on an oak, for example, blend into a whisper of the same average pitch but vastly greater volume, so too the whisperings of a great many individual trees merge into the well-known murmur of the forest.

Roaring of the Mountain.

When a mountain well wooded along and near its top is crossed by a wind approximately at right angles to its axis, as indicated in Fig. 8, it often happens, particularly during winter when there are no protecting leaves on the trees (or at any time if the forest is pine), that, in the leeward valley, one hears a low sighing or moaning noise which, as the wind over the crest grows to a gale, gradually swells to a cataract roar. This, too, is only another instance, but a most striking one, at times even awe-inspiring, of the combined effects of myriads upon myriads of æeolian whispers, accentuated, indeed, along the valley through their crude focusing by the descending winds.

Odds and Ends.

In addition to the above, there also are numerous other sounds that might, more or less justly, be called meteorological, such as the *rustle of leaves,* due to the rubbing together of the foliage as trees and branches are shaken by the wind; the *roar and whir of the tornado,* due to the wrecking by the storm of all things in its path, to the wind eddies engendered by every obstruction, and to the more or less continuous rumble of thunder; the *patter of rain,* due to the successive falling of innumerable drops onto a roof, pavement, compact soil, and the like, or into a body of water; the *rattle of sleet* (frozen raindrops), due to the driving of the small ice pellets against any hard object—the windowpane, for instance; the *clatter of hail,* due to the fall of relatively large lumps of ice onto a roof, or other hard surface, and even (occasionally reported in connection with severe storms) to their striking together in mid-air; the *detonations of meteorites,* due to violent disruptions owing to their sudden and intense heating; the *sizzle of St. Elmo's fire,* the faint crackle of the constant stream of feeble electric discharges from mast tips or other points thus strangely illuminated; the *swish of the aurora,* due, apparently, to autosuggestion, and hence wholly subjective; and, of course, many more. But the explanations of all are easy if not immediately obvious, and hence even their further listing is quite unnecessary.

The Obligatory Use of the Metric System in Japan. CH. ED. GUILLAUME. (*Comptes Rendus,* March 29, 1921.)—The telegram from Shirio Kikkawa, Director of the Bureau of Weights and Measures at Tokio, announcing the adoption of the law rendering obligatory the use of the metric system in the Japanese Empire, must have been very welcome to the great metrologist at Sevres. In Japan, the metric system became legal in 1893. This was followed by a series of regulations aiming to accustom the people to the new units, and now these preparatory measures have logically culminated in compulsory adoption.

In 1913 the Parliament at Peking entered upon a similar program. China is now in the preparatory stages, and this is the case also in Siam. The action of Japan will, no doubt, greatly influence the other nations of the Orient.

G. F. S.

The Introduction into France of the Lacquer Industry from the Far East. MARIE-YVONNE LEMAIRE. (*Génie Civile*, February 26, 1921.)—The trees of which lacquer is the latex are diminishing in number in China and Japan while, on the other hand, the culture is attaining considerable proportions in Tonquin. Indeed, this country is the sole exporter of lacquer. During the war the technical employment of this substance was introduced into France by Verneuil, who had had much to do with the establishment of the industry and with the cultivation of the trees in Tonquin. After trying various European varnishes it was decided to lacquer the screws and other parts of airplanes. Here the unalterable character of the covering joined to its ability to bend without cracking proved of high value in keeping the blades well polished and contributed to the mechanical efficiency of propulsion. Those little brown men with flat noses so common in France in war time, the Annamites, did this work, using the methods they had learned in Asia. Nothing was to be desired so far as the success of the operation was concerned, but great skill and a long time were needed for the production of the finished product. The French Society for Indochinese Lacquers is seeking to reduce the cost of the process and has already solved some of the problems and is making progress with others. The time required for the hardening of the liquid has been reduced and in general it may be said that the industry is well on the way to be established in France on a modern basis, though the rate of exchange between the mother country and her foreign colony intrudes difficulties into the road to success.

G. F. S.

Potash from Nebraska Lakes. (*U. S. Geological Survey Press Bulletin No. 467*, February, 1921.)—Until 1915 the United States produced no potash salts from native material except wood ashes, but in that year potash was produced from kelp, dusts from cement kilns, and alunite, and from the alkali lakes of western Nebraska. The possibility of developing the reserves of raw material from the first three of these sources has been studied and reported on by the United States Bureau of Soils, of the Department of Agriculture, and the United States Geological Survey, of the Department of the Interior, but no Government report has heretofore been issued on the potash resources of Nebraska. In 1918 W. B. Hicks, of the Geological Survey, spent three months in the alkali lake region of Nebraska, visiting the plants and the productive lakes; collecting samples of brine, water, sand, and mud for analysis; and making a general study of the region. The information he obtained has been studied and careful estimates have been made of the quantity of potash salts in these lakes. These estimates and notes concerning the probable source of the potash salts are contained in Bulletin 715-I.

DETERMINATION OF THE DIRECTION OF ATMOSPHERIC DISTURBANCES OR STATIC IN RADIO TELEGRAPHY.*

BY

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THE accidental discovery that the atmospheric disturbances, or static, come from more or less definite directions [1] was made independently by a number of observers in this country during the summer of 1918 in connection with the work then being done at various places to insure more perfect reception of European signals. It was then noted that along the coast of New England and the Middle States, the static appeared to come in general from the southwest. Very few quantitative observations, however, were made, but a general impression prevailed that the source of disturbance very probably lay in the hot plains of the Southwestern United States or Mexico.

WINTER AND SPRING, 1920.

In order to study static during the months when it is too weak in Washington to be of value for investigation, the writer was sent to Porto Rico in February, 1920.

San Juan.—On February 26th the apparatus was set up on the Naval radio reservation in San Juan near the old fortress San Geronimo, the instruments being sheltered in a tent. For the measurement of strength of signals and of the direction of the static it was not convenient to construct a swinging loop of sufficient size to permit satisfactory observations without amplification. Therefore, two standard 10 turn loops 50 ft. long and 8 ft. high with 6 inch spacing were placed at right angles to each other, with the apparatus so provided with switches that either one could be used alone or the two in parallel combination, either directly or in opposition.

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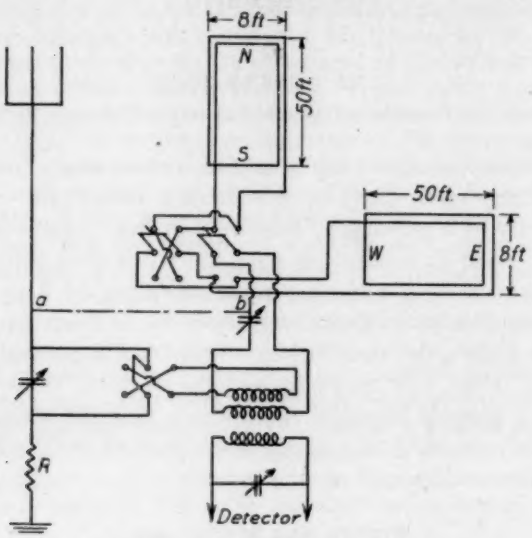
* Communicated by the Author.

[1] Note: Suggestions that static might be directional had been made earlier by Marconi, Pickard and others. See G. W. Pickard, *Proc. I. R. E.*, Vol. 8, p. 358, 1920.

The system was rendered unidirectional in the usual way by combining it with a small antenna. The circuits are shown in Fig. 1. This arrangement gave readings in eight directions, or

FIG. 1.



Circuit for study of static characteristic curve.

every 45° around the compass, and values could be interpolated so that the directions were known with a fair accuracy to within about 15°.

TABLE I.

Typical Observations on Southerly Static; San Geronimo, March 15.		*Observations During Static Storm: Static Mainly W by N but with much Local; Cayey, April 16.*	
Direction.	Audibility.	Direction.	Audibility.
N	6	N	200
NE	20	NE	100
E	40	E	80
SE	60	SE	100
S	70	S	100
SW	40	SW	150
W	30	W	300
NW	30	NW	200

A typical set of readings is given under the date of March 15th in Table I. Here it is seen that the larger part of the static came from a point a little east of south. During February and

March the variation of the strength of the static with wave length was very noticeable, as is indicated under March 9th in Table II, the intensity increasing twenty times between 7000 and 18,000 metres. This is in marked contrast with the results at Cayey during the heavy static of April 14th, Table II, when it is seen that the intensity remains almost unchanged between the same limits.

Loiza.—On March 19th the receiving apparatus was moved about twenty miles east of San Juan and about four miles from the ocean. The antenna loop system was identical with that at San Geronimo. The observations were continued here until March 31st, being taken in part by Gunner Taylor. The results here were similar in character to those at San Geronimo, though signals were somewhat weaker.

Cayey.—The observations at Cayey, altitude 1300 ft., 30

TABLE II.

Increase of Static with Wave-Length.

San Geronimo, March 9.		*Cayey (Static Storm), April 14.*	
Wave-lengths, metres.	Audibility.	Wave-lengths, metres.	Audibility.
7,000	2	7,000	80
10,000	10	10,000	100
13,000	16		
18,000	40	18,000	100

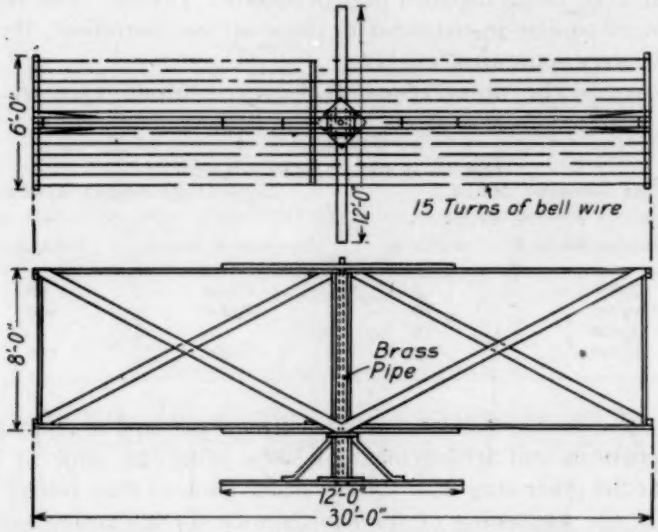
miles from the north coast, extended from April 2nd to April 15th, the apparatus and arrangement of loops being the same as were used at the other stations. Observations showed that, taking into account the weakening of the signals with the advancing season, the reception at Cayey is decidedly superior to the stations along the north coast, while with the exception of the static storm, April 14th to 19th, the static conditions are more favorable. During this period the static, which had been mainly from the south in March, shifted so as to come principally from a little north of west (see Table I), and, since the periods of receiving difficulties seemed to be identical at Otter Cliffs and Cayey, it was concluded that the disturbances came from a common source. The afternoon static along the Atlantic Coast of the Northern United States had been found in general to come approximately from the southwest. The two lines of static direction from Otter Cliffs and Cayey would then cross each other in Mexico.

SUMMER OF 1920.

In the summer work of 1920 the attempt was made to extend our knowledge of the direction of static to cover the Pacific Coast region and to render our information regarding the conditions on the East Coast and in Porto Rico more definite.

The apparatus used was as follows: The swinging loop of 15 turns, 30 ft. long, 8 ft. high and 4.5 inch spacing is shown in Fig. 2, while the circuits used are shown in Fig. 3. The parallel tuned circuit in the antenna simplifies the tuning of long waves on

FIG. 2.

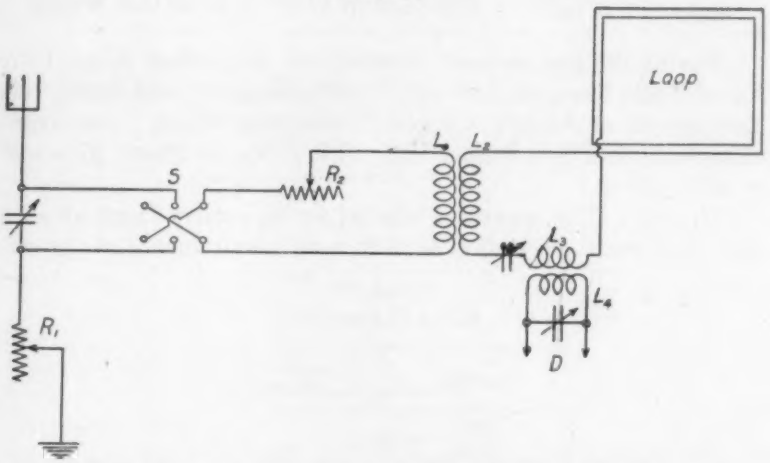


the small antenna and also seems to give a better balance than is obtainable with series tuning. The resistance R_1, 5000 to 30,000 ohms, serves to reduce the signal strength on the antenna to approximately that of the loop, while R_2, 200 to 1000 ohms, broadens the tune and enables the coupling to be changed without a too rapid shift of phase, thus rendering a complete balance easy. The balancing antenna used at different stations varied considerably in size. A single wire 100 ft. long and 30 to 50 ft. high was found to be satisfactory. The arrangement of coupling between the antenna and loop, as shown in Fig. 3, renders the loop unidirectional. With the switch S in one position, signals are received from one side while those from the opposite are cut off,

while with the switch reversed, signals are received only from the opposite side. Similar unidirectional combinations can be made between an antenna and a pair of underwater or underground wires, or, in fact, between any ordinary antenna and any type of directional collector.

For the determination of static direction the loop is turned and the coupling L_1L_2 adjusted so that when the switch S is thrown in one direction the static is a maximum, while with the switch in the opposite direction it is a minimum. The absolute direction in which the signals are strengthened and weakened with

FIG. 3.



the switch in a certain direction is best determined by observations on a station in a known direction. When this is determined it is advisable to place a mark on one side of the loop corresponding to a mark on the switch, to indicate that the signals from this side of the loop are strengthened with the switch in the marked position. When the general direction of the static has been determined as described, the loop is turned to a position approximately at right angles to the indicated direction of the static. Then the switch S is rapidly reversed, the loop at the same time being moved slowly until the position is obtained where the sound of the static on the telephones is of the same intensity with the switch in its two positions. For exact readings the position of the loop expressed in degrees should be observed at which a difference in the

intensity of the static is just detectable on each side of the zone of equality. In the mean position between these two points, the loop is exactly at right angles to the static. This method of determining static direction is far more accurate than that of the simple unbalanced loop (radio compass). In fact, good readings can be obtained by the balanced method when no difference at all in intensity can be observed with the simple loop.

TABLE III.

Changes in Direction of Static with the Season.

San Geronimo, March 1–18.	*Loiza, March 19–31.*	*Cayey, April 14–25.*
80 per cent. South 20 per cent. W by N	50 per cent. South 50 per cent. W by N	30 per cent. South 70 per cent. W by N

During the past summer observations were taken daily at the Naval Radio Research Laboratory (Washington), and during certain periods at Astoria, Oregon; Bremerton, Wash.; San Francisco, Cal., and San Diego, Cal., with a few in Porto Rico and at other points.

Astoria.—The apparatus was set up on a dairy ranch about a mile from the radio station so as to avoid the influence of the station antenna and excessively strong interference. The loop was of the type already described and the antenna was a single wire running along the ridge pole of a barn 25 or 30 feet from the ground. The receiving instruments were covered by a tent and the work was carried on with the help of Radio Aid Marriott, of the Puget Sound Navy Yard, and his assistant. Observations were made between July 21st and July 31st, and the results of the measurement of static direction are given in Table IV. It was found in general that while the static was irregular in its direc-

TABLE IV.

Astoria Observations.

Direction.	Number of times observed.
NE	8
ENE	19
E	3
ESE	8
SE	8
S	1

Estimated accuracy 5°–15°.

tion, the individual observations fell into groups, the largest group indicating disturbances from a point about 20° north of east. There seemed to be little connection between static and ordinary weather conditions.

Bremerton.—At Bremerton, as no suitable place was found in the Navy Yard, the loop was set up on a vacant lot near Mr. Marriott's house, with the instruments in a tent as at Astoria. The balancing antenna, about 90 feet long, ran to a pole in a neighboring lot.

Observations were begun on July 26th and Table V shows the summary of the directional observations up to August 23rd. From Table V it is seen that the observations are more irregular than

TABLE V.

Bremerton Observations.

Direction.	Number of times observed.
WNW	1
NW	3
N	1
NE	4
ENE	5
E	13
ESE	13
SE	27
SSE	2

Estimated accuracy 5°–15°.

at Astoria, on a few days even coming from the seaward side, no doubt on account of the Olympic range of mountains which lies between Bremerton and the ocean. In spite of the irregularity there seems to be a considerable concentration of static from the southeast.

San Francisco.—The loop was here set up on the highest point of Goat Island, using as a balancing antenna a two-wire antenna about 50 feet high, originally intended for short wave spark work. Table VI shows the directional observations between August 11th and 31st. It is seen at once that the directivity of the static is entirely different from that observed at Astoria and Bremerton. Instead of being scattered over an arc of nearly 180°, all the observations except one, which may have been influenced by some local conditions, fall within an arc of 10°. This condition is

remarkably favorable for a static barrage for reception from the west.

San Diego.—In San Diego the loop was placed in front of the distant control receiving station on North Island, with the receiving set in one of the receiving booths of the station. The observations, extending from August 26th to September 10th, are shown in Table VII, the wave length in most of the observations being about 11,000 metres. Here, as in San Francisco, the static was sharply directional from a point just south of east, none of the

TABLE VI.

San Francisco Observations.

Wave-length.....8,000–12,000 metres.

Date and time.	Direction of static.
Aug. 11: 3 P.M.	E
12: 10 A.M.	E
13: 2 P.M.	4° S of E
14: 3 P.M.	E
16: 10 A.M.	E
16: 3: 30 P.M.	4° S of E
17: 5: 00 P.M.	5° S of E
18: 4 P.M.	9° S of E
19: 3 P.M.	9° S of E
20: 2 P.M.	10° S of E
21: 3 P.M.	8° S of E
23: 4 P.M.	2° S of E
24: 1 P.M.	4° S of E
25: 3 P.M.	8° S of E
29: 6: 30 P.M.	8° S of E
30: 2 P.M.	8° S of E
31: 4 P.M.	3° S of E

Estimated accuracy 2°–4°.

observations differing by more than a few degrees from this direction. The static intensity in general was not very different at the two places, with bad days perhaps a little more frequent at San Diego.

Washington.—During the summer, observations on the direction of static were made twice a day at the Naval Radio Research Laboratory. A summary of the afternoon results, July 1st to September 15th, is given in Table VIII. It was found that the direction of static is less sharply defined than at San Francisco and San Diego and that the reception barrages are generally much less perfect. The prevailing direction appears to be about 30° south

of west, with a few observations scattered all the way between west and south.

Porto Rico.—Through some misunderstanding only a few ob-

TABLE VII.

San Diego Observations.

Wave-length.....11,000–17,000 metres.

Date and time.	Direction of static.	Audibility.*
Aug. 26 : 3 P.M.	10° S of E	40
27 : 11 A.M.	E	40
27 : 3 P.M.	E	40
28 : 3 P.M.	5° N of E	10
30 : 3 P.M.	10° S of E	30
31 : 11 A.M.	10° S of E	20
Sept. 1 : 3 P.M.	10° S of E	15
2 : 3 : 30 P.M.	10° S of E	8
3 : 4 P.M.	10° S of E	8
5 : 3 P.M.	10° S of E	..
8 : 11 A.M.	E	20
10 : 3 P.M.	E	40

Estimated accuracy 2°–5°, but absolute direction less accurately known than in San Francisco.

* Without amplification.

servations on the direction of static have been forwarded from Porto Rico during the summer, but these indicate that the prevailing static has come from the south just as was observed last

TABLE VIII.

Washington Observations.

Direction.	Number of times observed.
W	1
W by S	5
WSW	25
SW by W	22
SW	11
SW by S	6
S	4

Estimated accuracy 3°–10°

winter, instead of from a point slightly north of west, as found in the early spring experiments.

Our knowledge regarding the direction of static on the Gulf and Atlantic Coasts of our southern states is very meagre, but

the little information available indicates that around New Orleans it comes mainly from a little west of south, while at Charleston it comes in part from the mountains a little north of west and in part from the southwest as at the more northern Atlantic Coast stations.

We may summarize our knowledge of directional static in the United States as follows:

1. The static on the Atlantic Coast of the United States comes in general from directions lying between south and west, largely from the direction of Mexico, but partly from the Allegheny Mountains.

2. The few observations on the Gulf Coast indicate a direction roughly southwest, *i.e.*, from Mexico.

3. On the Pacific Coast static is weaker than on the Atlantic and seems to come for the most part from nearby centres. In the north it is diffuse, but much of it seems to come from definite local centres among the mountains. Mr. Marriott has called attention to the fact that both at Bremerton and at Astoria a large part of the static comes from the direction of Mt. Ranier, an isolated peak and the highest in that part of the world. Further south, at San Francisco and San Diego, static is sharply directional and practically always comes from centres nearly east and probably among the nearby mountains.

4. In Porto Rico, according to our observations, static comes in general from one of two directions, either from a little east of south, probably from a centre in South America, or from a centre in the direction of southern Mexico a little north of west. This last centre may also be the one which produces the southwest static in the eastern United States. In Porto Rico there is also during the warmer months considerable diffuse static of local origin.

5. In general we may conclude that static comes from the land rather than from the sea, and when it appears to come from the sea there is generally land in the given direction at no great distance.

6. It may be, judging from the analogy of signals, that static which increases with wave length in a marked degree as that at Washington and the southerly static in Porto Rico, comes from a great distance; while the static that varies little with wave length, as at San Francisco and San Diego, comes from centres not far away.

7. In Washington it is generally observed that the late afternoon static in summer is much more sharply directional than that

of the forenoon, and that the directivity frequently becomes more pronounced as the static becomes more severe.

8. Two types of static in respect to tuning have been noted in our laboratory, one giving a pure shock effect is heard simultaneously over a wide range of wave lengths, and one in which the crashes are not heard simultaneously at different wave lengths. This last we have called the spectrum type, since it appears to consist of a large number of independent waves of different lengths forming a continuous static spectrum. There is some reason to believe that the spectrum type forms a large part of the directive static.

9. At present it is impossible to formulate any completely satisfactory theory of the origin of static, but it appears probable that it originates in the upper atmosphere in powerful discharges between air bodies at different potentials,[2] though it is difficult to understand how such discharges which give rise to electrical waves more powerful than those from the largest radio station, can take place without luminous phenomena. If the disturbing waves are formed in this way in the upper atmosphere, the wave front undoubtedly spreads out until it reaches the earth, where it grounds itself exactly like the radio waves from an aeroplane and then moves off with a practically vertical wave front as if it had come from an antenna on the earth's surface.

The results of the observations thus far made, fragmentary as they are, indicate plainly the importance of taking static directional observations wherever radio stations are situated, and warrant plans for a general static survey which shall extend eventually to all parts of the world.

On the Resistance of Copper Sulphate in Glycerine. A. GILMOUR. (*Phil. Mag.*, March, 1921.)—When a high resistance is needed that has small capacity it is found that a solution of copper sulphate in glycerine answers well. Such solutions are quite free from polarization. They are, however, hygroscopic and should be sealed to avoid contact with the air. Tables are given of the specific resistance of solutions of different concentrations.

An interesting *obiter dictum* is, "Glycerine has been known for a long time as a solvent of very wide range—at least as extensive as that of water."

G.F.S.

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[2] See Pickard's article cited.

Does an Accelerated Electron Necessarily Radiate Energy on the Classical Theory? S. R. MILNER. (*Phil. Mag.*, March, 1921.) —An electron whose velocity changes, either in direction or amount, is believed to send out energy in the form of electro-magnetic waves. An electron, forming part of an atom and moving about the central positive charge of the nucleus, is accelerated and ought to emit energy. This loss of energy should result in a progressive change in its velocity or in some change in its orbit. There is great difficulty in reconciling this conclusion with the observed fact of the permanence of the atom. "This question is of fundamental importance in modern theory, and would, I imagine, at the present time receive an affirmative answer from most physicists. Some apology seems necessary for attempting to open the question again at this date; and I should not have ventured to do so, but for the result of the consideration of a certain concrete case of accelerated electronic motion which is amenable to an accurate mathematical treatment. This example shows that it is possible to obtain, even on the classical theory, a solution for a particular case of the accelerated motion of charges, which satisfies completely both Maxwell's equations and the mechanical laws which characterize a conservative system, without any irreversible radiation of energy. A study of it enables us, I think, to prove that a certain step made in the deduction on the classical theory of the general necessity for radiation is not invariably a valid one, and to show that a comparatively minor modification of the boundary conditions of the solution is sufficient to do away with radiation in at any rate one case of accelerated motion."

G.F.S.

The Use of Cables for the Support of the Roofs of Workshops and Hangars. LEINEKUGEL-LE COCQ. (*Génie Civile*, March 5, 1921.)—Though the supporting of roofs in this way is far from new, it has assumed some importance recently in France, especially where a large space free from pillars is to be covered, as in hangars for airplanes and dirigibles. In the latter case this method of support makes it possible to roll to one side the whole side of the hangar nearly 500 feet in length, thus immensely facilitating the stowing away of the balloon even in a wind.

G. F. S.

Fixation of Nitrogen by Marine Algæ.—BENJAMIN MOORE, EDWARD WHITLEY, and T. ARTHUR WEBSTER (*Proc. Royal Soc. London*, 1921, B, xcii, 51–60) have demonstrated the fixation of elementary nitrogen by marine algæ in the presence of sunlight or full daylight. The elementary nitrogen is derived from the atmosphere and is dissolved in the sea water; it is converted into organic nitrogenous compounds by the algæ which obtain the necessary carbon from the bicarbonates of calcium and magnesium present in the sea water.

J. S. H.

THE STRUCTURE OF THE PHOTOGRAPHIC IMAGE.*

BY

C. E. KENNETH MEES, D.Sc.

Director of the Research Laboratory, Eastman Kodak Company, Rochester, N. Y.

THE UNEXPOSED EMULSION.

WHEN a photographic emulsion is examined under a microscope, the sensitive silver halide which is distributed in the gelatine is seen to consist of crystals of several forms and of many different sizes (Fig. 1). These crystals are chiefly in the form of triangles or hexagons, some of the hexagons being irregular, while occasionally a thin rod-shaped crystal is to be seen. After careful study,[1] it has been determined that all these crystals belong to the regular or cubic system, but that instead of belonging to the group of crystals of which sodium chloride is typical, silver bromide crystallizes in the same crystal class as the alums. The flat crystals are produced by the development of the basal planes in preference to others, and in the case of the rod-like crystals truncation occurs in two dimensions, but these rods still belong to the same crystal class as the flat plates. As a general rule, the plate-like crystals of silver bromide are about 1/15th of their diameter in thickness, and they are found in the coating with their greatest surface parallel to the upper surface of the gelatine, this position being determined by the drying down of the coated emulsion.

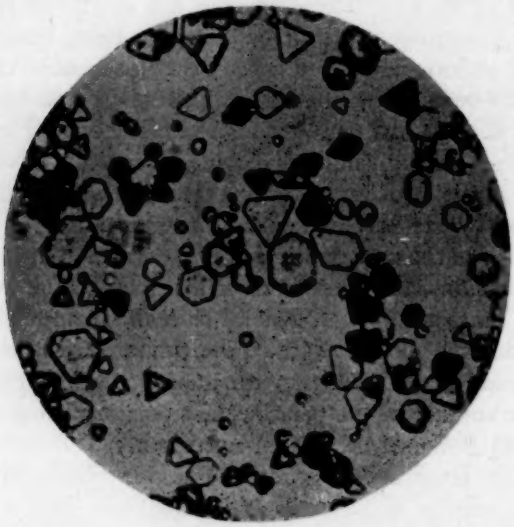
When an emulsion is examined under polarized light, the crystals are seen to be strained and to produce double refraction, and in many cases these strains extend into the gelatine as if the dry gelatine were strained by the presence of the crystals. It has not yet been determined to what the strains in the crystals are due. It has been suggested that, on the whole, it is probable that the crystals contain gelatine and that the strain is due either to this or to the presence of silver iodide. All commercial emulsions contain some iodide, which does not crystallize out separately, but which enters into the structure of the silver bromide crystals and

* Presented at a meeting of the Section of Photography and Microscopy held Thursday, December 2, 1920. Communication No. 109 from the Research Laboratory, Eastman Kodak Company.

[1] Monograph on "Silver Bromide Grain," Eastman Kodak Company, 1921.

results in an increase of sensitiveness in the silver bromide in spite of the fact that silver iodide displays very little sensitiveness when used in an emulsion by itself. It is possible that the iodine atoms enter into the crystal structure, being substituted for bromide atoms. In this case, the crystal lattice will be deformed by the volume of the iodine atoms, so that the crystal is in a state of strain and therefore readier to react under the influence of light. In order to investigate this hypothesis, a study of the crystal lattice of silver bromide with and without iodide should be made by the methods of X-ray analysis, a beam of X-rays being passed through

FIG. 1.



Crystals in a silver bromide emulsion.

the crystals and the diffraction pattern studied. It may be possible by comparison of the patterns produced by crystals of pure silver bromide and by crystals in which some iodine has been substituted for the bromine to detect any deformation of the lattice produced by the substitution.

Since the emulsion grains are definitely crystalline, their character will be determined when the emulsion is precipitated, though it may be modified by subsequent treatment such as continued heat or digestion with ammonia. The conditions of precipitation of crystals from solution have recently been investigated both

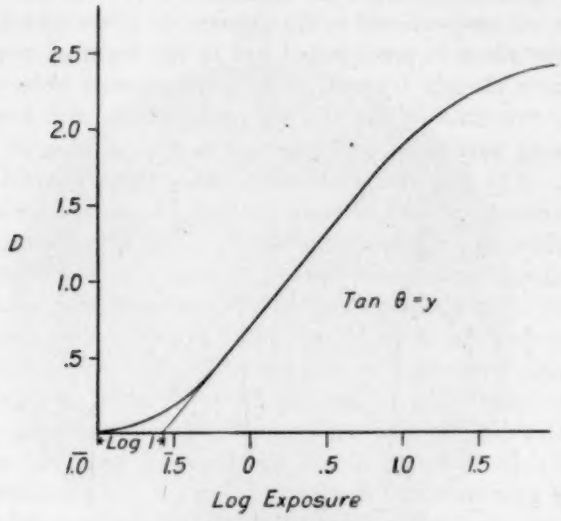
experimentally and theoretically, and the form of the precipitate has been found to depend principally upon the concentration and other conditions existing when the precipitation is made.

Photographic emulsions are formed by the addition of moderately concentrated silver nitrate solutions to bromide solutions of similar concentration in the presence of some gelatine and of an excess of soluble bromide. If we examine the precipitate produced at different stages during the addition of the silver nitrate solution, we shall find that as we continue to add silver, the number of crystalline grains increases, as would be expected, but that the increase is not proportional to the amount of silver added, so that some of the silver is precipitated not in the form of new grains but on grains already formed; that is, the crystals grow not only in number but also in size during precipitation, the first grains formed being very small and growing as the addition of silver is continued. The size of the silver bromide grains formed depends upon the amount of free bromide present, on the temperature, the concentration, and the rate of addition of the silver solution.

The photographic properties of an emulsion will depend upon the number of grains of different sizes present, and, in addition, upon the sensitiveness of the individual grains of each size. Now, photographic properties are expressed by the *characteristic* curve of the emulsion; that is, by the curve showing the growth of density after development corresponding to an increasing series of exposures. In order to obtain the curve, a series of exposures increasing geometrically is given. Thus, if the emulsion is held at a distance of 1 meter from a one candle power standard lamp, a convenient series of exposures would be ¼, ½, 1, 2, 4, 8, 16, 32, and 64 seconds. After development, the optical density of the deposit corresponding to each exposed area is measured, and a curve is drawn similar to that shown in Fig 2, which expresses the relation between the density and the exposure. For convenience, the exposure is plotted on a logarithmic scale so that the intervals between the steps are the same. Throughout a considerable portion of this curve, it will be seen that the density is proportional to the logarithmic exposure, and for this region the curve can be replaced by a straight line. Physically, this portion of the curve represents the range of light intensities in the original which is correctly reproduced by the absorption of light in the negative. At the beginning of the curve, in what is termed the *period of under-*

exposure, the increase of density is less than that which occurs through the straight line portion, the steepness of the curve rising from zero to the steepness of the straight line itself. In the period of over-exposure, density fails to rise proportionately with the increase of exposure and finally becomes constant, this constancy continuing for a long period, after which reversal sets in. In a paper published in the JOURNAL OF THE FRANKLIN INSTITUTE some years ago,[2] it was suggested that the shape of this curve

FIG. 2.



Characteristic curve.

should depend upon the distribution of the different sizes of grain in an emulsion, and, as an example of the dependence, a curve was given for a homogeneous emulsion which it was thought should give a simple curve with short over- and under-exposure portions (see Fig. 3), while it was thought that a curve having a longer straight line portion would correspond to greater variation in the size of grain of the emulsion, the grains of various sizes distributed around a mean replacing the greater uniformity of those of an emulsion, giving a curve with a short straight line portion.

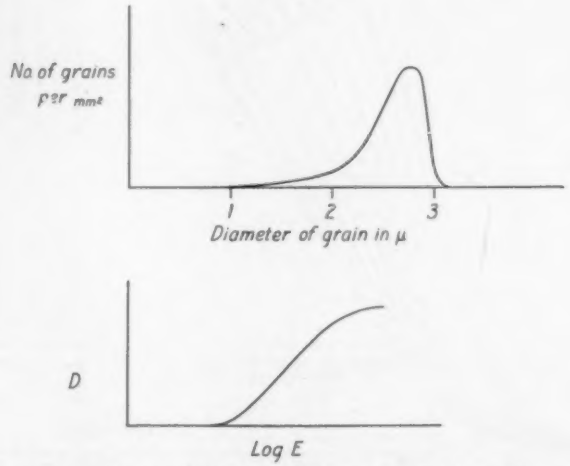
Dr. Ross[3] has recently investigated mathematically the rela-

[2] C. E. K. Mees, JOUR. FRANK. INST., 1915, p. 141.

[3] F. E. Ross, *Jour. Am. Opt. Soc.*, 1920, p. 255.

tion between the shape of the curve and the distribution of the grain. He has assumed that the grains can be considered as divided into groups of grains of approximately the same size, the sensitivity factor of the groups varying in geometrical progression, so that the grains of each group have twice the sensitiveness of those of the group next to it. With every other factor kept constant, the shapes of the curves obtained by calculation are found to depend on the number of groups assumed to be present. In Fig. 4 are shown the curves obtained on the assumption that 1, 2, 3, and so on groups of grains are present, the number of groups being indicated by N. It will be seen that, as the number of groups increases, the length of

FIG. 3.

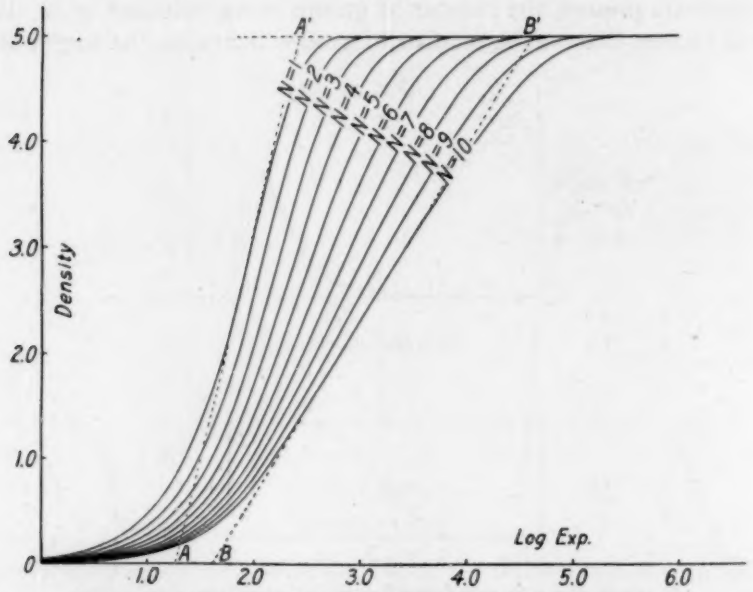


Suggested relation between frequency grain curve and characteristic curve.

the straight line portion of the curve as measured in exposure units also increases. When one group only is assumed to be present, the formula calculated by Dr. Ross would give the effective length of the projection of the straight line portion on the exposure axis as 15 exposure units. With 5 groups of grains, this would increase to 55; with 8, to 290; and with 10, to 1000. At the same time, the steepness of the curve corresponding to the maximum contrast obtainable diminishes, the maximum contrast for one group being approximately 0.82 D; for 5 groups, 0.58 D; 8 groups, 0.40 D: and 10 groups, 0.34 D, where D is the maximum

density obtained from infinite exposure. Thus, a curve with one group of grains present would correspond to the properties of a process emulsion, having a short straight line portion and a very high maximum contrast, while a curve calculated for the 10 group, having an effective range of sensitiveness between the groups of 1 to 512, would correspond to a portrait emulsion with a long straight line portion and moderate contrast. This is in agreement with the views of Slade and Higson,[4] who ascribe the properties of a process emulsion to the uniformity of its grains.

FIG. 4.



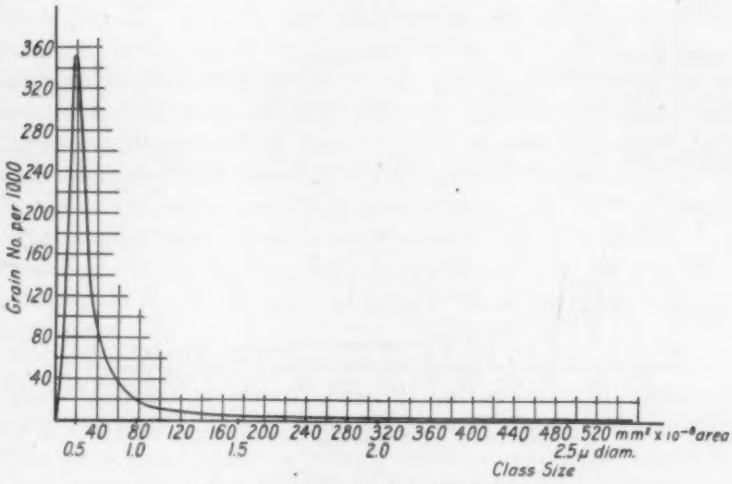
Characteristic curve calculated for different numbers of grain groups.

Up to the present, very little experimental work has been published on the distribution of different sizes of silver halide grains, the only work that has given results depending upon the actual measurement of a large number of grains and the classification of the results. Thus, if an emulsion is spread out thinly upon a miscroscopic slide, so that only one layer of grains is obtained, this is then photomicrographed at a very high magnification—2000 to 3000 diameters, for instance—this copy is enlarged about 5

[4] *Phot. J.*, 1919, Vol. 59, p. 200.

diameters, and a planimeter applied to measure the areas of the grains, it is then possible to construct a curve showing the relation between the area and the frequency with which grains of a given area occur.[5] While this process is laborious, it is quite possible to get excellent results with it. A curve showing the relation between the diameter of the grains and the frequency with which they occur is shown in Fig. 5; it will be seen that this curve is distinguished by the sharp point of maximum frequency at a diameter of .4μ. If, however, instead of plotting the number of the grains, we plot the total effective area of each size of grain,

FIG. 5.



Number of grains plotted against their area.

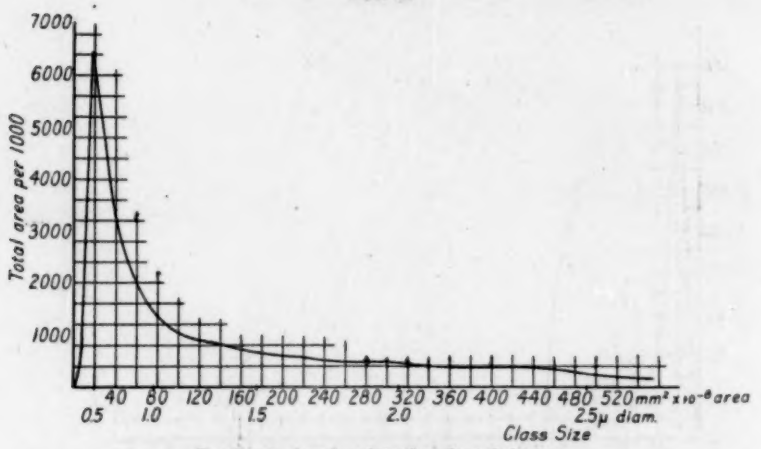
which is really the important characteristic of the grains, since the light absorbed depends upon the effective area and not upon the diameter of the single grains, we get the curve shown in Fig. 6, which may be taken as a first approximation to the true experimental distribution curve of an emulsion. This line of investigation must, of course, be pursued much further before the results obtained from it can be applied to the investigation of the relation between the grain distribution and the photographic properties of the emulsion, but it is to be hoped that this work will eventually prove successful in clearing up that relation.

[5] S. E. Sheppard and E. P. Wightman, *J. Phys. Chem.*, 1921, Vol. 25, p. 181.

In addition to measurements made by photomicrography, it may be possible to measure the frequency with which grains of a given size occur in a photographic emulsion by automatic separation of the grains, this method depending upon physical effects due to the difference in size such as would occur in sedimentation or similar methods of separation.[5]

When the relation between the characteristic curve of an emulsion and the frequency with which the grains of different sizes occur was discussed in 1915, it was assumed that grains of any size require the same amount of energy to make them develop-

FIG. 6.



Total area of grains plotted against their area.

able, and that consequently a given unit of energy would produce an amount of silver which would depend upon the mass of the grain by which it was absorbed. This would make large grains effectively more sensitive; that is, they would produce a greater density of silver than small grains owing to their size. This assumption was not based on any experimental evidence, but was the simplest assumption to make in the absence of any facts. There is now good reason to believe that it is not true generally and that grains of different emulsions, at any rate, even when of the same size, show specific differences in sensitiveness. In the case of grains of the same emulsion, an investigation of the distribution of sensitiveness according to size can be made experimentally.

Svedberg has recently published a study of the relative sen-

sitiveness of grains of different sizes.[6] He diluted an emulsion with water so as to obtain a considerable separation of the grains and placed in the diluted emulsion a glass slide which was then drained and dried. In this way, a layer is obtained which is only one grain thick, and it may be assumed that the grains can be attacked by the developer without any question of penetration being involved. The prepared plates were exposed for different times, and after development the silver was removed by means of a silver solvent, leaving the undeveloped grains intact. In this way Svedberg was able to determine by difference the grains which had been made developable by exposure to light. He classified the grains in four groups: those which had areas from 0 to 6 square μ, from 6 to 12, 12 to 24, and 24 upwards. By making use of the known covering power of grains of silver, his measurements can be recalculated to obtain the curves giving the relation between density and exposure for the different groups of grains. These curves are shown in Fig. 7, and it will be seen that the different sizes of grains show very clearly a difference in sensitiveness, so that the different sizes of grains in an emulsion must be considered to show specific differences in sensitiveness. It is clear that by an extension of Svedberg's method, much information can be obtained as to the distribution of sensitiveness among the grains of an emulsion.

Slade and Higson[7] have measured the number of grains developable after exposure to light of various intensities, the time being held constant; or of constant intensity, the time being varied. They chose grains from a process emulsion which they state to be of uniform size, though probably the uniformity refers to only the larger grains, and there must have been a considerable number of smaller grains present unless some special method of separation was used.

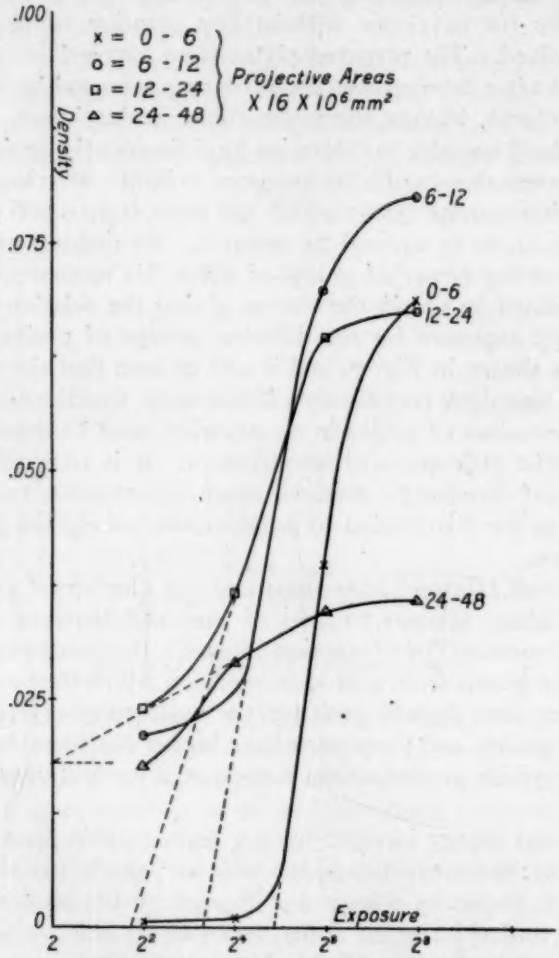
The total energy incident upon a photographic plate has two components: the intensity and the time for which it is allowed to act. It was shown by Bunsen and Roscoe for the combination of hydrogen and chlorine to form hydrochloric acid, which takes place under the influence of light, that the amount of acid produced was dependent only on the product of the intensity and the time; that is, on the energy used. But it was first shown by Abney, and

[6] T. Svedberg, *Zeit. f. Wiss. Phot.*, **20**, 36 (1920).

[7] *Proc. Roy. Soc.*, **A 98**, 154 (1920).

has often been confirmed by other workers, that this is not true for the photographic plate, and that, while with high intensities the law holds approximately, when the intensity is low, more

FIG. 7.



Characteristic curves of grains for different areas.

energy is required than if the intensity is high. There is a difference, then, between a plate exposed to a light of one candle meter intensity for 10 seconds and another exposed to a light of

1/100th candle meter for 1000 seconds. Slade and Higson find that this failure of the Bunsen-Roscoe law occurs also in their experiments, and they conclude that for high intensities the effect produced is proportional to the intensity, time being constant, while for low intensities the effect is proportional to the square of the intensity. They find a difference in this respect between the action of monochromatic and polychromatic light, a difference which appears to require further investigation.

It was first pointed out by Abney also that if an exposure is given in small installments so that the exposure is intermittent, these installments do not add perfectly. One hundred consecutive exposures of 1/100th of a second with pauses between them are not equal to a continuous exposure of one second, and the amount of the defect depends upon the duration of the single exposures and upon the duration of the pause. The behavior of the silver bromide grain in these respects is as though the energy going into it underwent a transformation of some kind, and if the energy is supplied rapidly, there is a smaller total leak than if it is supplied slowly. It is as if one were filling a tank by the aid of a leaky vessel; the quicker the liquid was transferred to the tank, the less liquid would have to be carried in order to fill it; and if one did it intermittently, all the liquid would run out of the vessel, and it would have to be refilled each time that the work was resumed; so that, if it were necessary to fill a tank by aid of a leaky vessel carrying water from a faucet, it would obviously be to one's interest to work as quickly and as continuously as possible. What the mechanism is in the grain which produces this result, how the energy is stored, and why it shows this leaking effect are still unsolved problems. It must be remembered that the grain apparently preserves its energy indefinitely once it has been exposed. It remains to be proved whether a grain which has been exposed to an amount of light insufficient to make it developable still preserves the energy which has fallen on it and when exposure is resumed behaves differently from a grain which has not been exposed at all.

It may be useful at this point to recapitulate briefly the present state of our knowledge with regard to the unexposed silver bromide grains. They are crystals belonging to the regular system, showing strain, containing in most emulsions some iodide as well as bromide, and probably containing absorbed in them other

substances such as soluble bromide, gelatine, etc. Their sizes are determined during the precipitation of the emulsion and are distributed over a range of diameters varying from ultra-microscopic grains below 1/10th μ in diameter to occasional grains as large as 10μ in diameter. The curve relating the sizes of grains to the number of each size present in an emulsion can be measured under the microscope and is probably related closely to the characteristic curve of the emulsion expressing the relation of density to exposure and therefore the photographic properties of the emulsion as a whole. Grains of the same size may vary in sensitiveness, and the sensitiveness of grains of different sizes in the same emulsion may vary from group to group. It can be shown that a geometrical relation between the sensitiveness of grains of different sizes is sufficient to account for the photographic properties displayed by emulsions prepared in different ways.

THE DEVELOPED IMAGE.

When they are developed, the silver bromide grains are transformed into metallic silver in a black spongy form, the silver occupying much the same position as the grains from which it was formed. The silver grains vary in structure according to the rate at which the silver is deposited, developers of low reduction potential giving grains which are more compact than those produced by the more usual developers. There is no experimental evidence, as far as I know, for the transfer of silver from one grain to another during development or for the growth of grains from silver in solution, at any rate under normal conditions. The silver bromide of each exposed grain is therefore transformed by development into an equivalent mass of silver.

The question has been raised as to whether the effective area of the developed silver grain is the same as or greater than the area of the silver halide grain from which it was formed. This point is under investigation at present. It is probable that the effective areas are substantially the same.

Since the deposit in a photographic plate is measured optically, a question of great importance is that of the relation of the absorption of light by the image to the mass of silver present. According to Beer's law, the amount of an absorbing material present in a solution, for instance, is proportional to the logarithm of the absorption, so that if we have a solution which transmits

1/10th of the light and another solution which transmits 1/100th of the light, the second solution will have twice the amount of absorbing material of the first solution. This is, of course, true only for monochromatic radiation or for substances which have no selective absorption—those which are black or gray. The silver image is of a sufficiently neutral color for this law to hold as far as selectivity is concerned, but the question arises as to whether we can assume that the law is valid for small particles such as are the grains of developed silver. This has been investigated both mathematically and experimentally.[8]

Experiment shows that to a high degree of approximation the amount of silver present in a photographic plate per unit area is proportional to the optical density, which is measured as the logarithm of the opacity, the opacity being the inverse of the transparency. Thus, the silver deposit which transmits 1/10th of the light is said to have an opacity of 10 and a density of unity. Such a deposit will correspond to 10 milligrams of silver per square decimeter of the photographic image. The mass of silver per square decimeter for unit density is called the *photometric constant,* and the question arises as to how far the photometric constant is dependent upon the size of the grains of developed silver and as to whether it is altogether independent of their distribution in the film. These problems have not yet been settled experimenally.

While it has been established beyond doubt that for a series of increasing exposures resulting in increasing densities, the photometric constant of a plate is a constant, it would seem probable that where the distribution of the same mass of silver throughout the thickness of the emulsion is quite different, the photometric constant may also be different. An extreme case would be given by images of the same optical density produced by ultra-violet light on the one hand and by X-rays on the other. In the first case, the grains of silver forming the image would be entirely upon the surface of the emulsion, while in the second they would be distributed uniformly throughout the depth of the emulsion. It would seem probable that in the second case, where the packing was not nearly so close, a greater mass of silver would be required for the same

[8] S. E. Sheppard and C. E. K. Mees, "Inves. of the Phot. Process," p. 39. Hurter and Driffield, "Latent Image and Development," *Phot. J.*, 1898, p. 145. J. M. Eder, "Handbuch, III," (1903), p. 220. P. G. Nutting, *Phil. Mag.*, 1913, 26, p. 423.

density than in the first case, where the grains are packed in the surface layer. If this is true for such an extreme case, it will also be true, though to a less degree, for images produced by light of different colors, since the penetration depends upon the wavelength of the light, and an image produced by red light, for instance, will be distributed to a greater depth in the emulsion than one produced by violet light.

THE GRAININESS OF THE IMAGE.

Since the final photographic image has a grain structure, it follows that under magnification any image must appear broken up to an extent depending upon the size and arrangement of the grains. In some cases, a developed deposit may appear grainy (that is, may show lack of homogeneity) to the unaided eye. The cause of this almost invariably is an agglomeration or grouping of the clumps made up of several of the ultimate silver particles which of themselves are so small as to be entirely beyond the resolving power of the unaided eye. When a deposit is viewed under magnifications insufficient to make just visible the ultimate grains, a lack of homogeneity is apparent which is due primarily to the presence of the first order clumps or aggregates composed of a few of these metallic silver particles. Under such conditions, the agglomerations of these clumps cease to have any appreciable effect on the grainy appearance of the deposit because the magnification is sufficient to separate widely the agglomeration centres. When the magnification is increased still further, so that the individual silver grains are easily visible, the graininess existing is due in a great measure to these grains themselves. It will be seen, therefore, that the lack of homogeneity in a photographic deposit depends upon various causes, according to the magnification under which the deposit is observed.

In speaking of grain, the scientific investigator usually refers to the ultimate silver halide particles of the emulsion, but when a case of lesser magnification is considered, such as exists, for instance, in the projection of motion pictures, or in the making of enlargements, the lack of homogeneity is due not to the ultimate grains themselves, but to aggregates of these grains composed of a relatively small number of the ultimate particles. To this type of non-homogeneity the word " graininess " is applied in order that it may be clearly distinguished from the effect produced by the reso-

lution of the individual grains under much higher magnifications. The grainy appearance which can be observed by the unaided eye is due to further agglomeration of these aggregates and should properly be referred to as *graininess of the second order*. It is evident, therefore, that there are three phases in the non-homogeneity of a photographic deposit: (*a*) graininess due to the existence of the individual particles of silver, (*b*) graininess due to clumping of these particles, and (*c*) graininess due to the agglomeration of the clumps. It should be understood that these phases are not separated by any distinct line of demarcation, but merge by imperceptible gradations into each other. This impression is the result not only of the size of the grains of which the deposit is composed, but also of the distribution and arrangement in groupings of various kinds.

The graininess may be measured and specified numerically, the method used depending upon the assumption that the graininess of a deposit is directly proportional to the distance at which the appearance of graininess becomes just imperceptible, provided that all other factors upon which depend the ability of the eye to distinguish homogeneity are constant. For instance, consider an enlargement of a photographic density, the degree of enlargement being such that the lack of homogeneity (*i.e.*, graininess) is readily apparent when observed at, let us say, ordinary reading distance (*i.e.*, 12 inches). Now, if the viewing distance be increased gradually, a point will finally be reached at which this lack of homogeneity will disappear and the entire print appear to be of uniform brightness, free from all visible texture. The distance at which this condition appears may be taken as a numerical measure of the graininess of the enlargement. If another enlargement made to the same degree of magnification be viewed under precisely similar conditions, the distance at which graininess disappears when compared to the distance at which graininess disappeared in the previous case will provide a numerical specification of the relative graininess of the two deposits. The determinations made in this manner would, however, be subject to large errors; the readings would vary from day to day and be dependent upon the individual characteristics of the observer. In order to eliminate this, a method was devised in which the distance at which the graininess to be measured is compared with the distance at which a structure of known period disappears, crossline screens being

chosen as the fixed structures with which the graininess is to be compared, so that a given graininess may be expressed by saying that it is equivalent to a screen of 3000 lines to an inch, it being implied by this that a 3000 line to the inch screen and the graininess in question would both just become visible at the same magnification.[9]

THE SHARPNESS OF IMAGES.

Since the image consists of grains, it is clear that the edge of an image, however sharp the edge of the theoretical image which produced it may have been, will be more or less ragged under high magnification. The sharpness of an edge in the case of a clearly defined image such as that of a spectral line will obviously be related to the size of the grain. Wadsworth considered that two lines should be separated in a photographic image if the distance between their centres was four times the diameter of a grain, but a very little experimenting will show that no such resolution as this can be attained, and that, especially with fine-grained materials, a much greater distance is required between two lines which are to be resolved clearly.

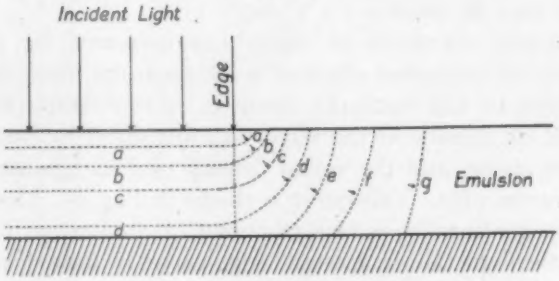
If we consider an optically sharp edge formed on a photographic material, such, for instance, as we might obtain by laying down on the material a razor blade, we shall realize that the light passing the edge will be reflected by the silver bromide grains of the emulsion, and that the light in the shadow of the edge will therefore be distributed somewhat as is shown in Fig. 8. We can calculate the falling off of the intensity according to the distance from the edge if we know the reflecting power of the grains of silver bromide, distribution, etc., or we can easily measure it by giving to such an edge a series of increasing exposures and then measuring the growth of the image inwards from the edge as the exposure is increased. Thus, suppose that a given exposure, a product of intensity and time, is required to form a visible deposit which we term the edge of the image. Then, for each intensity of the light reflected within the shadow of the edge there will be a corresponding time of exposure which will produce the image at the point corresponding to that intensity.

If, instead of a single edge, we use a narrow slit, we can measure its diameter for different times of exposure and draw a

[9] L. A. Jones and N. Deisch, JOUR. FRANK. INST., 1920, p. 657.

curve of the diameter against the exposure time. In this case, we shall find that the increase of diameter is proportional to the logarithm of the time of exposure, so that it follows the same law as the relation between the density and the exposure. The intensity of the light inside the shadow at the edge of an image on an emulsion falls off in the same way as the intensity of light passing into an absorbing medium. The constant of proportionality corresponding to the absorption coefficient may be called the *turbidity constant* (K), which can be obtained directly from the rate of the growth of the diameter of the image with exposure. The sharp-

FIG. 8.



Distribution of light at the edge of an image.

ness (S) may be defined as the rate of the fall of the density as the edge is crossed, or

$$S = \frac{\text{Change of density}}{\text{Distance from edge}}$$

and this can be separated into the two factors due to exposure and development, so that

$$\text{Sharpness} = \frac{\text{Change of density}}{\text{Change in log intensity}} \cdot \frac{\text{Change in log intensity}}{\text{Distance from the edge}}$$

Now, the growth of density with the logarithm of intensity is the development factor or *contrast* of the image, which is measured from the characteristic curve expressing the relation between density and exposure, generally written as γ. In reality, the development action at the edge of an image is not the same as for an area of uniform density, and the numerical value of γ is appreciably different. The diffusion conditions at the edge of the image modify the development very greatly, introducing complications which are of great importance in astronomical photography. The change of logarithm of intensity with distance, measured by the

growth of the image, is given by the coefficient which we have termed K. Therefore:

$$\text{Sharpness} = \frac{\gamma}{K}$$

It will be seen that this formula [10] ignores the grain size itself, the reason that fine grained emulsions give images sharper in outline than those of coarser grain being that fine grained emulsions usually have a high contrast (γ) and a low turbidity, so that they give good sharpness of an edge apart from all questions of grain. If materials are used, however, which have high turbidity and low contrast, they will not give sharp edged images even though the grain size may be small.

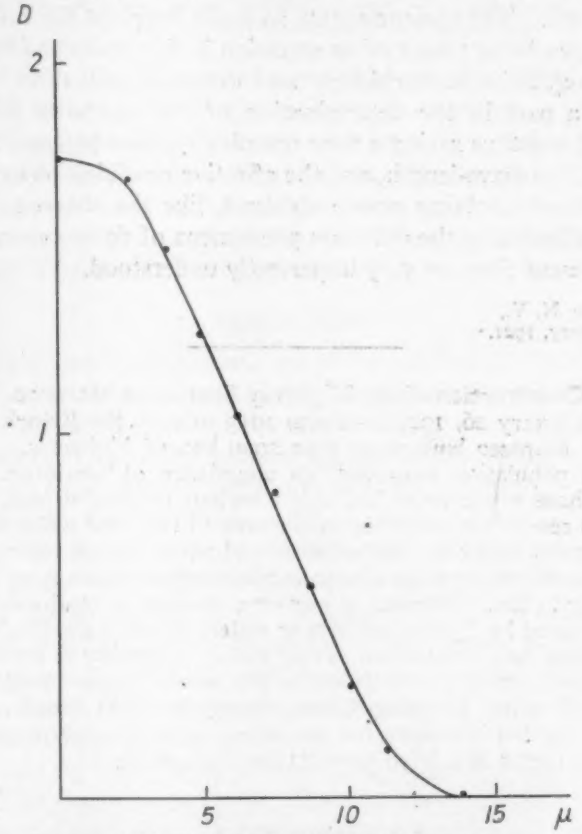
The actual sharpness of edges was measured by placing a razor blade or sharpened edges of a slit upon the material and allowing light to fall vertically upon it. After development, the falling off of density at the edge was measured by means of a microphotometer, and the actual density plotted against the distance from the edge. This curve is shown in Fig. 9. The slope of this curve may be taken as being a numerical measure of the sharpness. If the light falling upon the edge varies in wave-length, then it is found that the sharpness itself will vary with the wave-length. This would be expected, since both the gamma and the turbidity depend upon the wave-length. From the measured variation of γ and turbidity with wave-length, the sharpness wave-length curve can be computed, and the computed curve agrees sufficiently well with that observed to show that the general reasoning involved in sharpness is correct.

The form in which sharpness is of importance generally in photography, however, is that of resolving power. If we make a very small photograph of a picture and then examine it under a microscope, we shall, of course, find the detail broken up by the grain structure. We may, however, use a much finer grained plate without obtaining better detail, although the structure of the grain is now not so apparent. Finally, by using a plate of high resolving power, all the details of the picture appear sharp in spite of the great magnification which it has received. The resolving power of a plate is dependent upon two factors: upon sharpness, which in turn is dependent upon the photographic contrast and the turbidity,

[10] Cp. F. E. Ross, *Astrophys. J.*, 1920, **52**, p. 201.

and upon the graininess of the plate, which introduces a subjective factor of discrimination. Resolving power is found to vary with the wave-length in the same way as sharpness, thus indicating very clearly its dependence upon the latter, but in practice

FIG. 9.



Measured sharpness at the edge of an image.

it is convenient to use a method of measuring resolving power which does not depend upon the difficult measurement of the sharpness of the edge of an image, and for this purpose an image is formed of a converging grating in which the lines are always spaced at a distance apart equal to their width. This converging grating is photographed by means of a small camera at a consid-

erable distance, so that the image of the grating on the plate is only about one millimeter long, and since the spacing of the grating is known, a numerical expression for resolving power can be found by observing how far down the grating the image is resolved. This resolution is usually expressed in terms of the distance between two lines which will just be separated in the photograph. The measurements so made bear out the conclusion that the resolving power of an emulsion is the product of the three factors—graininess, turbidity, and contrast—all three factors playing a part in the determination of the resolving power as observed and thus giving a very complex relation between the size of grain, the wave-length, and the effective resolving power, while the practical resolving power obtained, like the sharpness of an edge, is affected by the diffusion phenomena of development which at the present time are very imperfectly understood.

ROCHESTER, N. Y.,
February, 1921.

The Construction of the Highway System in Morocco. (*Génie Civile*, February 26, 1921.)—From 1913 to 1919 the French Protectorate in Morocco built more than 2000 km. of highways. The indigenous population furnished an abundance of workmen at low wages whose employment had also a serious political aspect, since it helped to render contented the inhabitants of this land which had only recently come under French influence and which like all other parts of the earth suffered from the economic conditions resultant from the war.

Owing to fuel difficulties in war time mechanical road-rollers were often replaced by lighter and slower rollers drawn by animals. This arrangement had the merit of saving money, especially in the south of the country, where 5 or 6 francs a day would hire a camel and his driver. A roller, weighing 5 tons, drawn by eight camels, cost 40 centimes per ton-kilometer for operation, while a roller propelled by a gasoline motor cost from 50 to 75 per cent. more.

G. F. S.

The Constitution of the Alkali Metals. F. W. ASTON. (*Nature*, March 17, 1921.)—The method of positive ray analysis is applied to the alkali metals. Lithium has already been found to consist of two isotopes of atomic weights 6 and 7. Sodium atoms are of one kind only; potassium is made up of two isotopes having the atomic weights 41 and 39, the latter greatly preponderating. There are two rubidium isotopes, 85 and 87. Thus far only one type of cæsium atom has manifested itself, but the evidence in this case is not final.

G.F.S.

ANISOTROPIC LIQUIDS.*

BY

J. STEPH. VAN DER LINGEN, B.A.; F.P.S. (London);

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THE following researches were commenced at the University of Zurich in 1913, and were devoted to the elucidation of a point of much importance with regard to the real inner constitution of anisotropic liquids. To make the point of issue plain, it will be well to give a short account of some of the work that has been done on such liquids, and of the theories of their structure that have been advanced in recent years.

INTRODUCTION.

Solid Crystals and Their Optical Properties.—"The study of crystalline structure, both in its experimental and theoretical aspects, during the past century, has led to the conclusion that the whole of the physical, geometrical and mechanical properties of crystalline solids are in harmony with the following definition. A single individual crystal is a homogeneous structure, that is, a structure the parts of which are uniformly repeated throughout, so that, ignoring the boundaries, corresponding points have everywhere a similar environment. The correspondence between this statement and the facts is so complete as to prove definitely that the characteristic which distinguishes crystalline solids from other bodies, is this homogeneity of structure of the individuals of which they are composed.

"From the principle of structural homogeneity may be at once deduced all the various forms, in which the empirically observed fundamental laws of crystallography have been stated, such as the law of zones, the law of rational indices, etc., and it is to be concluded that the distinguishing feature of external regularity of form, assumed by an individual crystal, is correlated with the class of homogeneous structure to which it belongs."

Since the time of Bravais (1850) it has been accepted as axiomatic that the position of equilibrium of the molecules of a

* Communicated by Dr. Joseph S. Ames, Associate Editor.

crystalline body form some definite geometrical figure, whereas the molecules of all other bodies are irregularly distributed through space. The configuration of the centres of force determine the space-lattice of the crystal, and the type of the lattice is revealed by the external regularity of form of the rectilinear figures.

On account of the symmetrical arrangements of the centres of force in a space-lattice, a crystalline solid possesses definite elasticities along definite directions, and these elasticities are assumed to be responsible for the optical properties of crystals.

On account of their high order of symmetry, cubic crystals do not show double refraction, whereas pyramidal and rhombohedral crystals have only one direction along which double refraction does not take place, that is, they possess one optic axis, and are called uniaxial as distinguished from crystals possessing prismatic, oblique or anorthic symmetry, which are biaxial.

When *convergent* polarized light is transmitted along the optic axis of a uniaxial crystal, and the emergent beam is examined by a Nicol's prism, it is found that the crystal displays rings and crosses which are symmetrical about this axis. Similar symmetrical figures are displayed by biaxial crystals in convergent polarized light, but in this case, the figures are symmetrical about the two optic axes.

Furthermore, on account of the difference in the elasticities along different directions in a crystal, the coefficient of absorption of light sometimes varies to such an extent that the crystal assumes different colors in different orientations with regard to the direction of transmission of light, that is, it displays dichroism.

These optical properties are sometimes taken as an index to the class of symmetry to which a given crystal section belongs, *e.g.* rock sections. We shall discuss the converse argument when we review Vorländer's theory of anisotropic liquids.

ANISOTROPIC LIQUIDS.

In 1888 Reinitzer discovered that Cholesteryl benzoate melts at 140° C., and changes to a turbid fluid, which is double refracting up to 179° C., where it becomes isotropic,[1] and in 1890 Gattermann recorded similar phenomena in the case of p. azoxyanisole and p. azoxyphentole. Since Reinitzer's discovery, which was followed by numerous similar discoveries, and preparations of new compounds endowed with doubly refracting properties in the liquid

state, several theories have been advanced to account for this phenomenon.

THEORIES OF ANISOTROPIC LIQUIDS.

G. Tamman classified these anisotropic liquids under the heading of emulsions, and he attempted to explain the fact that the observed phenomena may be retained for days by assuming that the suspensions are endowed with a long life.[2]

This theory gives no solution to the optical properties, such as double refraction, dichroism, etc.; and it was on this account that Emil Bose,[3] after having reviewed the evidence in favor of and against the emulsion theory,[4] on the evidence of Vorländer's chemical researches,[5] assumed that the molecules of those substances which may pass into anisotropic liquids have the form of ellipsoids of revolution, and that "swarms" of such molecules move in aggregates in the liquid, and thus cause the optical phenomena.[6]

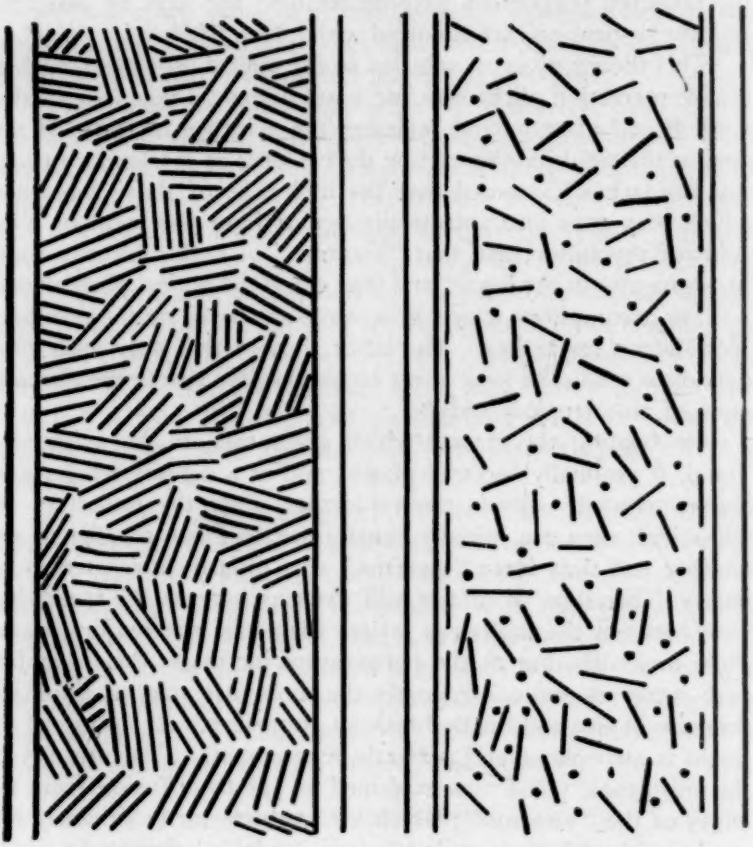
The assumptions which Bose made are based on the results of Vorländer's researches. The latter showed that only such compounds as consist of long linear molecules give rise to the phenomenon of anisotropic liquids.[5]

On heating the crystal which gives rise to the anisotropic liquid, it gradually becomes plastic, and at a definite temperature begins to melt. Bose's theory is that, since the molecules are ellipsoidal, they are initially constrained to move parallel to one another and thus form "swarms" of similarly orientated molecules. This state of affairs will exist as long as the mean free path between the molecules is less than half the major axis of these molecules, but as the temperature increases, the mean free path increases and consequently the molecular swarms gradually decrease in size and finally break up altogether. At this stage the liquid is amorphous and perfectly transparent. The turbidity of the anisotropic phase was explained as due to diffusion from the edges of the "swarms"; which are not necessarily similarly orientated although their molecules are similarly orientated (See *A* and *B*, Fig. 1). Subsequently Bose found that not only is the transition from Crystal ⟶ anisotropic liquid perfectly sharp and accompanied by a definite absorption of heat, but also: that the transition from anisotropic liquid ⟶ Isotropic liquid is gradual and is accompanied by a small absorption of heat;[7] moreover he also showed that under certain conditions thick layers of aniso-

tropic liquids are perfectly transparent.[8] This latter discovery is in accordance with the theory of swarms, whereas the emulsion theory is feelingly silent on this point, as well as on most of the optical phenomena.[9]

In order to test his theory, Bose argued as follows: When

FIG. 1.



the substance is in the anisotropic state, it consists of swarms of similarly orientated molecules, which will require a definite time to flow through a capillary tube when the diameter of the tube is large in comparison with the size of the individual swarms, and the time of efflux in this phase must be less than the time of efflux

when the liquid is isotropic, because in the latter case the molecules move in any direction, hence the efflux in the anisotropic phase must vary with the temperature, because the "swarms" first decrease in size and finally break up; that is, the rate of efflux increases as the size of the swarms decreases, but decreases when the haphazard motion sets in.

The optimum state of flow is when the velocity at the centre of the tube is a maximum and zero at the circumference, that is, when the product of the pressure P, and the time of efflux T, for unit volume is constant. Poiseuille's state of flow $P_p T = K$.

Now by increasing the pressure beyond a definite limit this relation should not hold because the flow becomes entirely different. In this state characterized by $P_h = K_h/T^n$, the swarms will be whirled against the sides of the tube, as well as haphazardly against one another, and will consequently break up. This state of affairs will favor the tendency of isotropy; consequently the rate of efflux near the transition point, under a high pressure, should become more and more nearly equal to the rate of efflux immediately beyond the transition point. In the isotropic region, however, the viscosity will be independent of the pressure, because there are no molecular swarms.[10]

In his experimental researches Bose found that the difference between the rates of efflux in the two regions did actually become less as the pressure increased and these results were thus considered a confirmation of his theory.

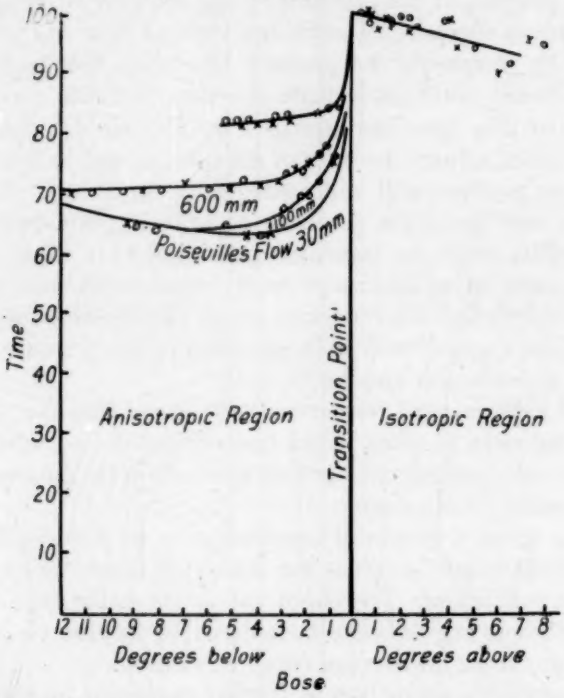
Fig. 2 gives a graphical representation of his results. The time of efflux is put = 100 at the transition point, where the viscosity is a maximum. The slight variations in the time of efflux in the isotropic region were considered to be due to errors of observation, hence an average curve was drawn.

This viscosity anomaly was further explained by considering the dimensions of the molecules, which flow axially out of the tube in the Poiseuille state and haphazardly under all conditions in the isotropic state. If they be ellipsoids of revolution whose axes are "*a.a.c*" where "*a*" is small in comparison with "*c*," the maximum viscosity is to the minimum viscosity as 3 : 2, that is, the viscosity in the anisotropic phase below the transition point is 2/3 of the viscosity just above the transition point. If the axes of the molecule are "*a,b,c*"—probably anisotropic liquids which have two anisotropic phases, this ratio may even become 1/3.[11]

PRESSURE AND VELOCITY EFFLUX THROUGH CAPILLARY TUBES.

At the instigation of Bose, F. A. Willers carried out a detailed set of observations on the variation of efflux with pressure in the case of pure emulsions, both below and above the critical temperature.[12] He showed conclusively that the same pressure-efflux variation observed in the case of anisotropic liquids is shown by emulsions, but there is this difference, that this variation is also

FIG. 2.

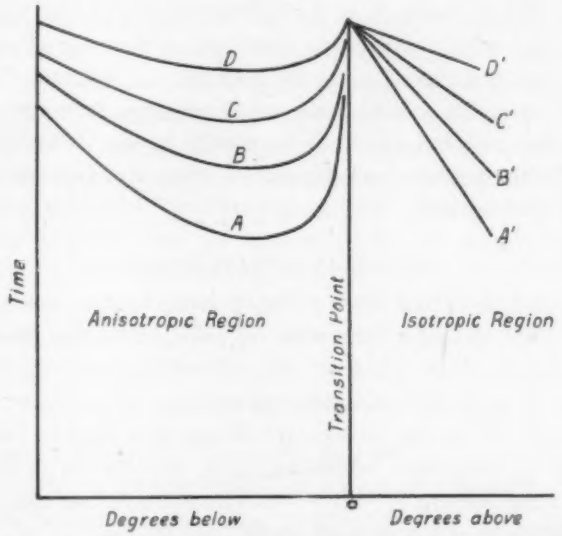


displayed beyond the critical temperature, that is, the constant pressure curves, plotted against the temperature below and above the critical temperature, have a similar type of slope. He arrived at the conclusion: "This work shows that the viscosity variation with pressure does not furnish any proof in favor of the different theories."

Emulsions—"Swarms".—Subsequently M. W. Neufeld showed that the viscosity of anisotropic liquids in the isotropic phase also varies with the pressure; and he pointed out that, if

Bose had continued his constant pressure curves for a range of temperatures in the isotropic phase, he would have found that the "near lying" points of limited observations were in reality each belonging to a smooth curve.[13] Hence these phenomena for anisotropic liquids and emulsions are identical (Fig. 3 according to Kruger). In 1908 Bose [14] pointed out the importance of investigating the influence of pressure on the efflux of liquids, and in 1909, subsequent to publication of Willer's results for emulsions, he gave a record of observations of the efflux of

FIG. 3.



pure liquids through capillary tubes.[15] This work which was published to draw attention to this important problem, was carried on by W. Sorkau, who arrived at the conclusion that there are three states of turbidity which are dependent on the pressure to which the liquid is subjected.[16] The second type, however, has been shown to be a transition "backwards and forwards" between the first type and the third type.[17]

In the Poiseuille state of flow the viscosity decreases with the temperature and the temperature coefficient depends upon the chemical constitution of the liquid.[18] In type one turbidity, the viscosity also decreases with the increase of temperature, and not only is this decrease uniform but also its coefficient is practically

the same for different substances. The third type, which we shall now designate "second" type, is wholly different from the first. Here the change of viscosity with temperature is practically zero.

Thus the states of flow are *Poiseuille, Turbidity One, Turbidity Two*, respectively as the pressure range is increased, representing the cases where: (1) There is a variable temperature coefficient of viscosity, depending on the chemical constitution; (2) a constant temperature coefficient which is independent of the chemical constitution; and, finally (3) no temperature coefficient or a small positive one.[19]

From these results it is to be concluded that the variation of the viscosity with pressure, as observed in the case of anisotropic liquids, does not depend upon the presence of "swarms."[20]

This variation of viscosity and pressure is common to all liquids; the criterion seems to lie wholly in the Poiseuille flow in which the temperature coefficient of viscosity depends upon the chemical constitution.

MOLECULAR SURFACE ENERGY.

We have seen that Bose's theory leads to the conception that an anisotropic liquid is in a state of association, and that it gradually becomes dissociated as the transition temperature is approached, because the molecular swarms become smaller.

Now if MV be the molecular volume of a liquid $(MV)^{\frac{2}{3}}$ will represent an area over which an equal number of molecules are spread, consequently $\gamma\ (MV)^{\frac{2}{3}}$ is the relative molecular surface energy, where γ is the surface energy per sq. cm.

Eötvös proposed the relation $\gamma\ (MV)^{\frac{2}{3}} = K\ (T - t')$ where T is the critical temperature, and t' the temperature of observation. This relation was subsequently modified to $\gamma\ (MV)^{\frac{2}{3}} = K\ (t - \delta)$ where δ is the intercept on the temperature axis obtained by plotting the former relation, which was found to be a linear function of t' up to about 6° from T.

This relation gives for the constant K the value of 2.12 erg/deg. for an unassociated liquid, that is, a liquid in which there are no molecular complexes. Hence $\frac{d}{dt}\left[\gamma(MV)^{\frac{2}{3}}\right] = 2.12$ erg/deg. for unassociated liquids; but if the liquid becomes associated or dissociated, Eötvös assumed that then MV will no longer

represent the molecular volume, but $\frac{MV}{x}$ where x is the degree of association. That is, $\frac{d}{dt}\left[\gamma\frac{(MV)^{2/3}}{x}\right]=K$ erg/deg. and thus $x^{2/3}=\frac{2.12}{K}$ or $x=\frac{(2.12)^{3/2}}{K}$. We may write $\mu=\gamma\frac{(MV)^{2/3}}{x}$

Eötvös pointed out that a smaller value than the normal indicates an association, whereas a larger value than the normal indicates a dissociation of the liquid.

The recent work of Jaeger and Kahn [21] on the two phases of anisotropic liquids clearly shows that the (μt) curves correspond to the two cases: "They show *two* branches, of which the first has regard to the anisotropic region, the second the isotropic liquid phase, and in all cases without exception, the first branch falls with an increase of temperature more rapidly than the second branch." From these observations the authors conclude that the theory of Eötvös does not hold for these substances. "According to Bose's theory one would expect an association in the anisotropic phase, on account of the (molecular) swarms, and a large dissociation factor in the isotropic phase when the swarms are broken up: Experiment, however, gives just the very opposite result."

MAGNETIC EFFECTS.

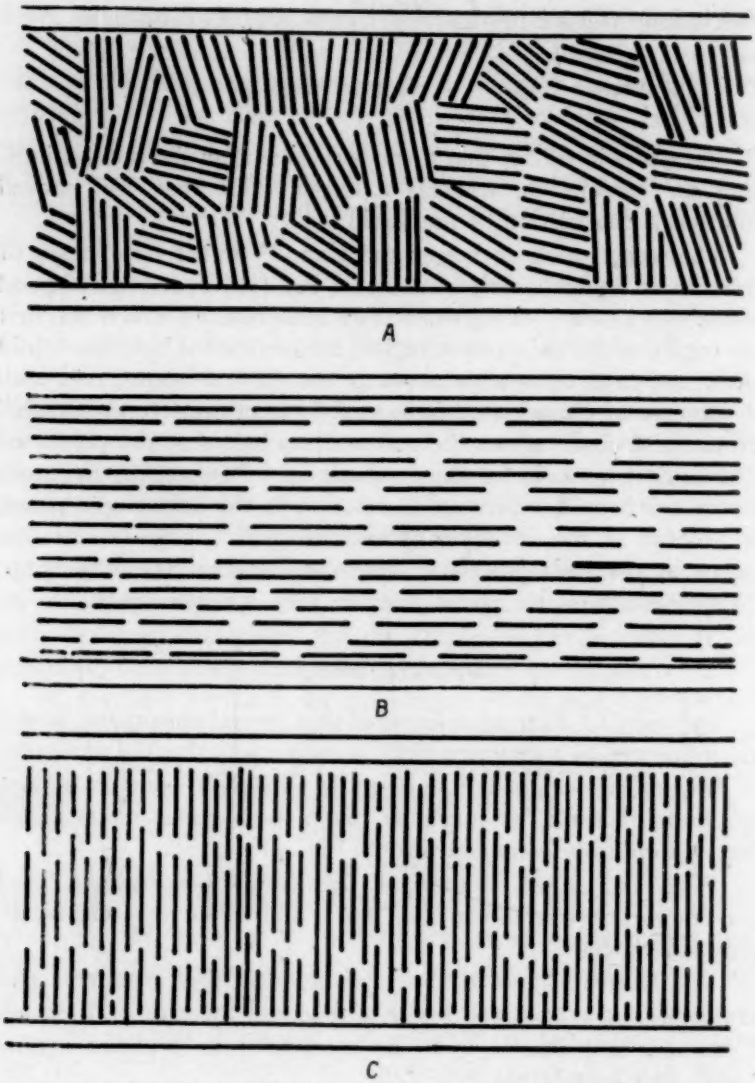
In 1900 O. Lehmann discovered that several anisotropic liquids are influenced by a magnetic field, in such a way that the molecules, or swarms, are orientated so as to lie with their optic axes along the lines of force, so much so that a turbid anisotropic liquid becomes optically homogeneous [22] (Fig. 4).

Bose and others confirmed Lehmann's observations, both for mixtures containing oil, etc., and also for chemically pure substances.[23]

W. Nernst draws the conclusion that this magnetic phenomenon is a crucial test between the rival theories of Bose and Lehmann, and that it is to be considered as evidence against Lehmann's contentions.[24]

In order to test Bose's "theory of swarms," Neufeld used substances whose swarms could be orientated in a magnetic field, so that the long axes, *i.e.*, optic axes, lie along the lines of force.[25]

FIG. 4.



A, no magnetic field; *B*, magnetic field perpendicular to glass plate, according to Lehmann *C*, magnetic field perpendicular to glass plate, according to Bose.

On Vorländer's concept the optic axis is in some cases at right angles to the long axis of the molecules. In such cases the long axis places itself perpendicular to the lines of force.

On letting the substance flow through a capillary tube, placed perpendicularly to the lines of force, one would expect a slower rate of efflux—in the domain for which Poiseuille's equation holds good—when the magnetic field is "on," on account of the internal friction due to the turning effect on the swarms and their breaking up; moreover, *one would expect a quicker efflux just above the transition point*—isotropic phase—in the strong magnetic field *than just below the transition point.* His experiments clearly show that there is no difference in the rate of efflux whether the molecular "swarms" axes are perpendicular or parallel to the sides of the capillary tube; that is, the magnetic field has no influence whatsoever on the rate of efflux, whether the liquid be in the anisotropic or isotropic phase; moreover,[26] he also showed that the pressure efflux is independent of the diameter of the capillary tube.

Consequently we conclude that the magnetic phenomenon does not give any evidence in favor of Bose's theory.

OTTO LEHMANN'S THEORY.

We have seen that a crystal is defined as a solid body in which the atoms are grouped according to some geometrical configuration of centres of force, and that this statement is supported both by the empirically observed laws of crystallography, and by the optical properties of crystals.

According to Lehmann, a crystal should be defined as an *anisotropic body which is endowed with the property of growth,* whether such a body be a liquid or a solid.[27] The anisotrophy of such a body does not necessarily imply optical anisotrophy, but it always does imply what we may call "polarity" with regard to the method of growth, and thus includes biological processes.[28]

The essential difference between this definition and that of crystallography is that the latter defines crystals as having a space-lattice. Lehmann's definition excludes isotropic bodies which have become optically anisotropic under the influence of external forces —e.g., glass in a magnetic field, certain gases in an electric field, and also optically active solutions. If, however, an isotropic body becomes anisotropic under certain conditions, and *if it be also*

endowed with the property of growth under those conditions, then according to Lehmann, it is a crystal, whether it possesses a space-lattice or not.

It is in this sense that Lehmann used the term "liquid crystal." He maintains that liquid crystals possess a space-lattice only when they are polyhedral in form, similar to solid polyhedral crystals, or when a very thin layer of the crystalline liquid is placed between similar crystalline plates, so that each of the plates has the same orientating effect on the molecules of the liquid.[29] If, however, the solution be placed between amorphous plates, or dissimilar crystalline plates, the solution becomes pseudoisotropic.[30]

The anisotropic properties of a body are, according to his theory, not dependent upon the structure of a space-lattice, but specifically upon the anisotropic properties of the molecules themselves, so that "if the molecules be irregularly orientated, even when they occupy the points in a regular lattice, such a body would not display anisotropic properties." [31]

Moreover, he maintains that a change in the space-lattice of a crystal is not accomplished by any change in the vapor pressure, melting-point, and solubility of the crystal. Where changes in the physical properties do take place, they are attributed by him to a change in the structure of the molecules themselves.[32] This is essentially the difference between the theories of Bose and of Lehmann.

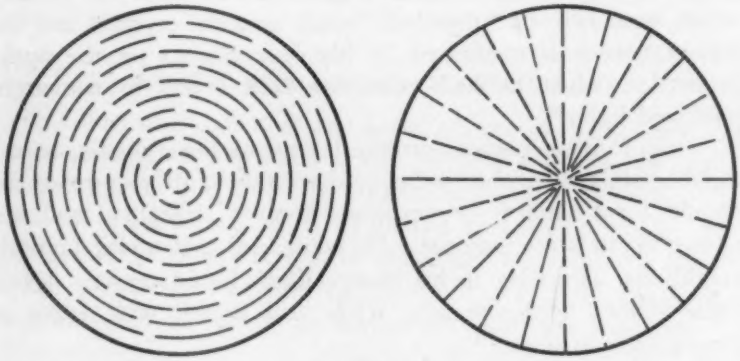
These conceptions of Lehmann, which he explained fully in numerous works,[33] are in direct contradiction to the theory of the identity of molecules in the so-called three states of matter, so much so that Nernst [34] denies the existence of liquid crystals.

We have seen that Bose, on the evidence of Vorländer's chemical researches, assumed that the molecules are ellipsoidal; Lehmann initially assumed that the molecules were spindle-shaped, but on the evidence of his later researches, he rejected this form and assumed a lamellar structure for the molecules. Lehmann's evidence is founded on the following argument (Fig. 5; see *A* and *B*).

In the case of carefully cleaned glass plates,[35] the molecules which form the pseudoisotropic layers set themselves in a definite direction with regard to the glass surface. In this condition the liquid behaves optically like a uniaxial crystal, with its axis per-

pendicular to the surface. Now when the liquid is placed in a glass tube and if it be allowed to flow out, the optical properties will indicate how the molecules are placed with regard to the glass walls. On examining the optical properties under these conditions, he found that the molecules are placed with respect to the glass walls of the tube exactly as they were in the case of cover slides. From this phenomenon he concludes that the molecules cannot be spindles standing normally to the glass walls, because then a turning moment, due to variation of the velocity from the centre to the side of the tube, would rotate those molecules which

FIG. 5.



are near the walls of the tube, and thus change the optical phenomenon; hence he decides that the molecules must be "leaflets," whose magnetic and optic axes are normal to their surface. The evidences now reviewed clearly show:

(I) The magnitude of Bose's swarms must be reduced in order to agree with the observations on the rates of efflux through narrow capillary tubes.[38]

(II) Either Eötvös' theory must be modified so as to include anisotropic liquids or Bose's theory must be dropped. Lehmann's theory, however, deals with molecules, and he considers physical changes in the constitution of the molecule itself responsible not only for polymorphism but also for association and dissociation.

The sole reason why Bose's theory is preferred by some to Lehmann's is simply because "it is in harmony with the treasured theories of molecular physics" and at the same time gives an explanation of the phenomenon of anisotropic liquids.

D. VORLÄNDER'S THEORY.

We have seen that Bose and Lehmann do not classify anisotropic liquids under the same heading as the generally accepted definition of solid crystals. Vorländer, however, contends that anisotropic liquids are in reality solid uniaxial crystals, whose elastic constants are small, that is, there is still a small cohesion between the component parts of the space-lattice.[37] According to him, all anisotropic liquids are in reality uniaxial crystals, even though they are derived from the most complex organic compounds. This assertion is far-reaching, because complex organic compounds generally give rise to optically biaxial crystals. Moreover, he asserted that the so-called pseudoisotropic layers—which term he calls "mystisch"—are uniaxial crystals, and that this statement is confirmed by his observations on the optical properties, when he had examined such layers in convergent polarized light.[38]

Now if these pseudoisotropic layers, or the globules, be uniaxial crystals, then when such liquid crystals solidify or grow, they should form squares or hexagons because tetragonal and hexagonal crystals are uniaxial. He contended that under favorable conditions, according to his observations, liquid crystals develop these shapes approximately, while still liquid, with edges approximately straight.[39]

Friedel and Granjean, however, clearly showed, subsequently, that these phenomena were due to a linear aggregation of globules and were caused by the apposition of two or more individual crystals, and that there is no geometrical similarity to the forms obtained in the case of solid crystals.[40] In our introduction we gave considerable space to the optical properties of crystalline solids, and showed that crystals may be divided into three main types according to their optical properties. Thus:

Cubic crystals are optically isotropic,
Hexagonal and Tetragonal crystals are optically uniaxial,
Orthorhombic, Monoclinic and Amorthic crystals are optically biaxial.

Now the converse argument that double refraction is due to crystal structure, hence anisotropic liquids are crystals, is not necessarily true because gases under certain conditions are doubly refracting, and crystalline structure cannot be attributed to gases.

Double refraction and dichroism, or plechroism, only indicate polarity of structure, which structure is not necessarily crystalline.

We may only attribute crystalline structure to gases in an electric field, and to liquids in a magnetic field as well as to optically active solutions, if we accept the theory that the molecules under all conditions are themselves crystalline in nature, and that their lattices may be similarly arranged by the application of external mechanical forces as well as by chemical affinity. The molecules thus which give rise to optical anisotropy must themselves be "polytropic" in nature. Growth will then only take place when the translatory motion is reduced to zero so that the component atoms only may continue to oscillate about their centres of equilibrium.

RÖNTGEN RAYS AND CRYSTAL STRUCTURE.

It will be seen that Bose and Lehmann on one hand deny that pseudoisotropic liquids have a space-lattice, whereas Vorländer definitely states that they are uniaxial crystals even though the forms are doubtful and their elasticities vanishingly small. The latter's theory cannot be put to the usual mechanical tests for elasticity, cleavage or cohesion, hence it was desirable that a crucial experiment should be devised to determine which of the two structures answered to the facts, and for this purpose Laue's recently devised method by X-ray research seemed excellently suited.

X-RAYS AND CRYSTAL STRUCTURE.

In the next paragraph we give a short summary of the method with special reference to the point at issue.

Until recently the theory of crystallography was supported principally by the analogy between crystal structure, polymorphism, and the morphotropic relations of various compounds, and the law of zones, rational indices, etc.; but there was no direct proof to show that the units of a crystal were actually arranged in a definite space-lattice. Microscopically this is impossible, because the shortest wave-length of visible light is only of the order 10^{-5} cm., whereas the atoms are of the order 10^{-8} cm. Under these conditions a crystal will act as a continuous medium for ordinary light, because the rays will not suffer diffraction because

of the smallness of the atoms in comparison with the wave-length of light.

After his discovery of X-rays, Röntgen tried to find some optical relations between these radiations and ordinary light. He was only successful in so far that he showed that their intensity follows the inverse square law; he could not, however, find any reflection or refraction.

Haga and Wind attempted to find a diffraction effect by passing these rays through a V-shaped slit. From their observations they concluded that the wave-length must be of the order 10^{-8} cm. Walter and Pohl, however, concluded that this method leads to the value 10^{-9} cm.

Subsequently Sommerfeld and Koch, independently, arrived at the conclusion that the quanta theory of Planck leads to the value 10^{-9} cm.

Now we see that crystallography and molecular physics affirm that the atoms or molecules are grouped according to some definite geometrical configuration of points, which form the space-lattices of crystals, and that the linear dimensions of atoms are of the order 10^{-8} cm. On the other hand, experiment and Planck's Radiation theory show that the wave-length of X-rays must be of the order 10^{-8} or 10^{-9} cm., *i.e.*, the probable wave-length is comparable to the dimensions of an atom or molecule in a regular space-lattice. To this must be added the evidence that Sagnac and Barkla showed that X-rays are scattered by solids.

These contentions led Max Laue to consider the crystal as an excellent three-dimensional diffraction grating for X-rays.[41]

The constants of this grating will thus, if they be known, give a mathematical expression of the positions of the directions along which the radiations diffracted from the atoms will reinforce each other. His anticipations were fully justified by the epoch-making experiments carried out by Friedrich and Knipping.

Since the publication of these results, numerous experiments have confirmed them; and the X-ray spectrum was soon mapped out as a particular region in the spectra of electromagnetic waves, and at the same time lattices of crystals were unravelled. The configuration of these loci of maximum intensity which may be recorded on a photographic plate is determined by the direction of transmission of the rays through the crystal, and naturally by

the type of grouping of the atoms in the space-lattice of the crystal.[42]

a. Point patterns, that is, patterns of points lying on conic sections.
b. Radial line patterns. These consist of lines radiating out from the central point, which point is due to direct transmission.
c. Ring patterns. These consist of zones whose intensity is constant for certain values of the radius drawn from the central point.
d. Patterns consisting of small irregularly shaped spots and broken lines.

The patterns under *a* are due to the projection of the diffracted cylindrical pencils—or small cones of rays in the case where the incident radiations are not parallel—on the plane of the photographic plate. These points are regular images of the openings in the diaphragm, provided that the crystal covers the whole of the opening, and this type of pattern indicates a regular space-lattice,[44] whereas the radial line patterns show that there is a transition grating, that is, the third elastic constant of the crystal is changing.[45]

The ring or zone pattern indicates that the crystal is made up of smaller crystals in which *one axis* is fixed in space. If an axis be placed normally through the central point of a symmetrical pattern of type (*a*), and if this be rotated round this axis, the equidistant points will trace out a zone of uniform intensity. The same effect will be produced if the crystals be rotated round the axis along which the incident rays travel.[46]

Patterns under *d* are due to irregularly orientated elements which constitute a microcrystalline body. Here the spots are images of the individual crystals which are covered by the incident pencil. The size of the diaphragm does not affect the size of these singularly distributed spots.[47]

Now it will be seen readily that when Röntgen rays are transmitted through a body and the emergent rays are recorded on a photographic plate, the pattern will indicate the nature of the architecture of the body, especially will it show whether a body be truly amorphous or crystalline.

OBJECT OF RESEARCH.

The object of our experiment was to find whether the pseudoisotropic layers of Lehmann and Bose have a space-lattice according to the contentions of Vorländer.

SELECTION OF SUBSTANCE.

The substances which we selected for this work were:

A. p. azoxyanisole
B. p. azoxyphenetole
C. anisaldazine
D. p. "cyanbenzalaminozimt-saure-akt-amylester"
or
"Slumpf's Cyanester."

The first three substances were taken because their molecules of "swarms" may be orientated in a magnetic field so that their principal or magnetic axis lies either along or perpendicular to the lines of force, and they are such that, when viewed along the lines, and normal to the lines, they display regular anisotropic properties of solid crystals, the phenomena being those generally associated with a uniaxial crystal cut normal and parallel to the optic axis respectively.[48]

This magnetic effect enables one to fix one axis in space, and thus the nature of the emergent Röntgen rays will determine whether the subordinate axes are also fixed in space, or whether they are, contrary to Vorländer's theory, but according to Lehmann and Bose, distributed at random.

"Stumpf's Cyanester" was used at the conclusion of our experiments because its refractive indices had been determined very accurately.[49]

APPARATUS.

In order to heat these substances to a fixed temperature, a pair of copper spirals were constructed out of two copper cones and four copper plates.

As these substances had to be placed in a magnetic field, equal lengths of copper wire were wound round the cones, so that the current passed in opposite directions round them. This avoided the turning moment of the magnetic field on the spirals as well as an extra orientating effect on the molecules of the anisotropic liquids.

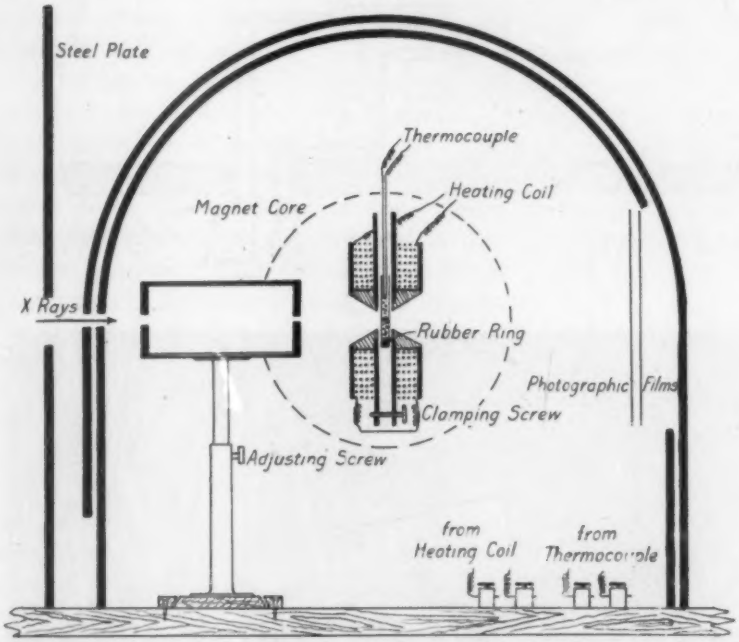
Between these spirals the substance experimented on is enclosed between two thin glass plates, which are kept in position by means of the three screws which clamp the spirals together.

The temperature of the substance between the glass plates was determined by a sensitive thermocouple. A good microscope, fitted for crystallographic work, was clamped to the midpoint of

a flat piece of brass, whose ends were attached to semicircular flat pieces of brass.

The under side of these flat semicircular pieces, which rested on the coils of the electro-magnet and thus carried the weight of the microscope, was lined with thick velvet, so as to protect the insulation of the coils. When this holder was placed over the coils, the pole pieces of the electro-magnet were between the objective and the object table of the microscope, consequently the solution, which

FIG. 6.



was placed between the pole pieces, could be examined without any difficulty.

Before the heating spirals were clamped in position, pads of wadding were glued to the pole pieces of the electro-magnet in order to minimize heating effects. Lead jackets were constructed so as to cover the whole of the electro-magnet.

In order to protect the X-ray tube a slab of soft iron was interposed between it and the electro-magnet. A narrow beam of X-rays was obtained by using a lead diaphragm similar to that originally used by Friedrich and Knipping.

Fig. 6 gives a section through the apparatus and shows the course of the X-ray, through the substance under investigation, to

FIG. 7.

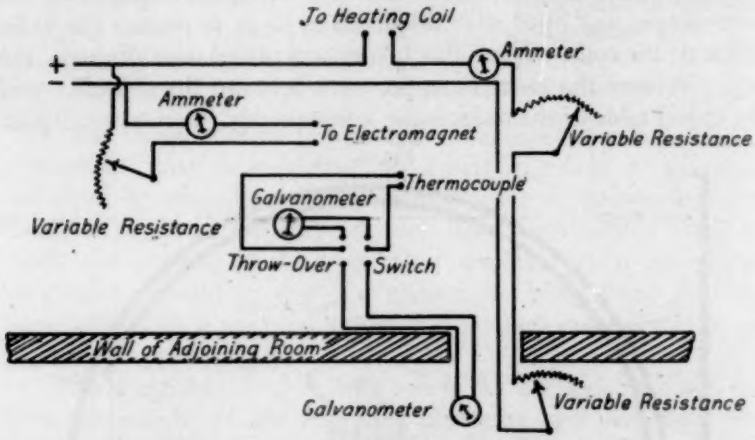


FIG. 8.

Apparatus ready for exposure.

the films. Fig. 7 shows the electrical connections, and the photograph shows the apparatus—together with the microscope and its holder—immediately before an exposure (photo).

METHOD OF EXPERIMENT.

The field strengths of the electro-magnet when the spirals were between the poles were determined by means of a standard bismuth spiral.

These values were recorded for a series of different current strength which were read off from an ammeter. Next, the deflections of the galvanometer were recorded for a range of temperatures of the hot junction of the thermocouple (iron-constantan). This hot junction was placed in an oil bath alongside of a standard 1/10° thermometer; the cold junction was kept in a funnel of melting ice.

A rubber ring 1 cm. in diameter was cut at a point and placed on a coverslip, which had been cleaned in H_2SO_4, hot water and finally dipped in ether and left to dry. A small quantity of the substance to be experimented upon was carefully powdered and placed inside this cut ring, and was covered with a similarly prepared glass plate. The size of the plates was: 0.17 mm. thick and 11 mm. square. This slide was carefully placed between the spirals so that the cut in the ring was uppermost.

The junction of the thermocouple was then placed in position and the spirals clamped between the padded pole pieces. A current was passed through the spirals and the microscope was focussed on the substance. On melting, air bubbles were expelled through the opening in the ring by gently screwing and unscrewing the spirals. Subsequently this method was modified as follows: Instead of the rubber rings, clean flat pieces of rubber were used. These pieces of rubber were cut so as to have an 8 mm. circular opening in the centre. This circular opening was then joined by a 1 mm. canal. This canal then contained the junction of the thermocouple.

RÖNTGEN RAYS AND ANISOTROPIC LIQUIDS.

Pseudoisotropic Layers.

Parazoxyanisole.—A slide of this substance was prepared as described above. After careful microscopic examination in a field of 5000 Gauss, it was heated from 118° to 136°, where it became amorphous, and allowed to cool gradually in the magnetic field.

After it had solidified, the diaphragm was placed in front of the slide in line with the focal spot of the anticathode of the tube.

This was done by focussing a cathetometer on the focal spot and moving the tube until the focal spot was midway between the poles of the electro-magnet and on the cross hairs of the telescope—during this process the spirals were removed.

The diaphragm was then illuminated from the tube side and was placed so that its openings were in line with the cross hairs and the focal spot. Next the slide was placed in position by centring its openings, and rotating it until the light from a pea lamp, attached in front of the telescope, was reflected back from the glass plates into the telescope. At a distance of 3.5 cm. behind the spirals, two sensitive X-ray films were placed. The first layer of lead and the magnetic screen were then placed in position, and the X-rays were transmitted through the diaphragm and the slide. This transmission was tested by placing a screen behind the window. After these preliminary observations had been made, the outer jacket was put over the electro-magnet. The objects of this experiment were to find whether the glass plates absorbed the diffracted rays from the thin layer of solid crystal, and also whether the substance crystallized into a homogeneous crystalline plate under the action of the magnetic field. After an exposure of four hours, the first film was developed, and it showed that the plate was crystalline, but not homogeneous, that is, it became microcrystalline on solidification, hence this layer which appeared optically homogeneous in the magnetic field became microcrystalline on solidification.

The second film was developed after an exposure of eight hours. This film, which was used as a check on the first, to eliminate film flaws, showed the same pattern of the fourth type, and also a large amount of dispersion.

On removing the slide, and examining it microscopically, the optical irregularity could be seen only slightly by rotating the slide between crossed nicols.

These results, like our preliminary ones, show that the molecules or "swarms of molecules" do not retain their orientation and secondly, that the glass plate does not absorb the diffracted rays to such an extent that a photogram cannot be obtained.

This slide measured about 0.3 mm.

A slide of the same substance 0.5 mm. thick was prepared and heated up to 118° C. It was carefully observed by means of the microscope to ensure that the layer was optically homogeneous.

The temperature was kept constant by observing the deflection of the galvanometer, and if necessary regulating the resistance in circuit.

The diaphragms, films, lead jackets and magnetic screen were placed in position and the exposure commenced.

RECORD OF RESULTS.

Paraazoxyanisole.

Thickness of Layer.	Magnetic Field.	Time of Exposure.	Nature of Photogram.
.05 cm.	5000 Gauss	8 hours	Only dispersion.
.05 cm.	5000 Gauss	16 hours	Increase in dispersion.
.03 cm.	5000 Gauss	15 hours	Dispersion.
.07 cm.	5000 Gauss	15 hours	Dispersion.

Temperature 118° C.

The same method of experimenting was used in the case of *Paraazoxyphentole.*

Thickness of Layer.	Magnetic Field.	Time of Exposure.	Nature of Photogram.
.03 cm.	5000 Gauss	15 hours	Dispersion.
.05 cm.	5000 Gauss	15 hours	Dispersion.
.07 cm.	5000 Gauss	15 hours	Dispersion.

Temperaure 140° C.

Anisaldazine.

A with a trace of olive oil; *B* pure.

A. 0.5 mm. thick in a field of 5000 Gauss. Time 10 hours. Dispersion.

B. 0.3 mm. thick in a field of 5000 Gauss. Time 9½ hours. Dispersion.

On account of the high temperature, 172° C., this substance caused a lot of trouble. Several experiments of shorter duration than *B* were interrupted on account of the insulation of the spirals giving way.

"CYANESTER OF STUMPF."

This substance was prepared for me in three degrees of purity *A, B, C* by Professor Werner, to whom we wish here to express our thanks. *C* was chemically pure. Layer of 1/10 mm. in the solid state gave no interference pattern, but layers of .2 gave patterns of a microcrystalline nature. An anisotropic layer of *A* showed no interference phenomena after an exposure of twelve hours—no magnetic field on. A similar layer of *C* gave the same result after an exposure of ten hours, at which stage we were forced to discontinue our investigations.

CONCLUSION.

These results clearly and definitely show that the pseudoisotropic layers of Lehmann and Bose do not possess homogeneity of structure as this term is understood in crystallography, nor is there any evidence to show that such layers are microcrystalline. Consequently we conclude that the above experiments show that such layers of anisotropic liquids do not possess a space-lattice; that is, the contention of Vorländer, based on the optical phenomena of such layers, cannot be accepted.

The uniform dispersion which was observed in each case is not due to the glass plates, as the author initially thought,[52] but is wholly due to the regularity of molecular structure of these anisotropic liquids, probably caused by similarly orientated ellipsoids one of whose axes only is fixed in space.

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[1] See Ch. 20 Neue Welt d. Flüssigen Kristalle, 1911. *Ann. d. Phys.*, 40, 401; 41, 525, 1890. *Ann. d. Phys.* (4), 2, 649, 1900.

[2] *Ann. d. Phys.* (4), 4, 524, 1901.

[3] *Phys. Zeit.*, 8, 347, 1907. Bose defends Tamman's theory against Schenck and Eichwald, who contend that there is a sudden transition from anisotropic liquid to isotropic liquid, and that this phenomenon is not shown by emulsions.

[4] *Phys. Zeit.*, 8, 513, 1907. Reviews the emulsion theory and "without wishing to enter the fight about liquid crystals" merely suggests his theory of swarms.

[5] *Ber. d. Chem. Gesell.*, 40, 1970, 1907; 41, 2035, 1908, etc.

[6] *Phys. Zeit.*, 10, 230, 1909, for full theory.

[7] *Phys. Zeit.*, 9, 169, 1908, conjointly with Conrat.

[8] *Phys. Zeit.*, 9, 707, 1908. This discovery made Bose give up the emulsion theory.

[9] *Phys. Zeit.*, 8, 42, 1907. (Lehmann's questions concerning "Emulsions.")

[10] *Phys. Zeit.*, 10, 32, 1908.

[11] *Phys. Zeit.*, 10, 230, 1909.

[12] *Phys. Zeit.*, 10, 244, 1909.

[13] DR. ING: Dissertation, Danzig, 1913. These researches were suggested by Bose, but were carried out under Kruger. Here we may say that Bose was the prime factor for inspiring young men to carry out researches on his viscosity anomaly. He, Bose, left Danzig to take up duties at La Plata, where he supervised the building of his laboratory. He met Professor W. Sorkau and inspired him to carry on his researches. (See Bose and Lauert, *Phys. Zeit.*, 10, 406, 1909), on the anomaly for pure liquids. The published results of Sorkau, who carried out the work in Bose's laboratory, were not seen in print by Bose, who, in the prime of his life and exceptionally brilliant activities, was laid to rest on the 25th day of May, 1911.

[14] *Phys. Zeit.*, 10, 32, 1908.

[15] *Phys. Zeit.*, 10, 406, 1909. Conjointly with Rauert. (Paper was sent from Lissabon—Bose was on his way to La Plata; see 4.)

[30] *Phys. Zeit.*, **12**, 582, 1911; **13**, 805, 1912.

[31] See MIE, *Phys. Zeit.*, **14**, 93, 1913.

[32] SMILES: "The Relation Between Chemical Constitution and Some Physical Properties." Ramsay Series, 1910.

[33] SCHAEFER and FRANKENBERG: *Phys. Zeit.*, **14**, 89, 1913.

[34] *Phys. Zeit.*, **15**, 582, 1914. Sorkau says: "Die Graphischen Darstellung im logarithmischen Druck Geschwindigkeits-Koordinatensystem, lehren dass zwei Strömungsarten zu unterscheiden sind." He does not accept the small positive value given by Schaefer and Frankenberg. Equations deduced from his students' observations are: Poiseuille's equation $P\,T = K$ where P is the pressure and T the time of efflux for a given volume; K, a constant depending on the chemical constitution, the length of the tube, and the fourth power of the radius. Turbidity types:

First $P^{0.55}\,T\theta^{/273} = K_h$ Called Hagen's flow by Sorkau. θ = the temperature of the liquid.

Second $P^{0.65}\,T \quad = K_f$ Called the Frictionless flow.

In Type 1 K depends on the dimensions of the tube in the same way as K in the Poiseuille flow.

In Type 2 the liquid flows out like a solid mass, whose radius is smaller than that of the tube, which is bounded by an immovable cylindrical layer of liquid. The thickness of this "Lot-wasserschicht" also varies directly as the length of the tube.

[35] *Proc. Kgl. Akad. d. Wetchsch.*, Amsterdam, Vol. 18, pt. 1, 297.

Substance: p. azoxyanisole.

$\frac{d\mu}{dt} = 7.1$ erg/deg. between 115 C and 126 C. Anisotropic phase.

$\frac{d\mu}{dt} = 12.2$ erg/deg. between 126 C and 133 C.

$\frac{d\mu}{dt} = 3.45$ erg/deg. to 2.2 erg/deg. at 190° C. Isotropic phase.

p. azoxyphenetole:

$\frac{d\mu}{dt} = 6.6$ to 4.89 erg/deg. between 143 C and 164 C. Anisotropic phase.

$\frac{d\mu}{dt} = 2.68$ erg/deg. Isotropic phase.

Anisaldazine.

$\frac{d\mu}{dt} = 11.0$, 15.2, and even 19.3 erg/deg. Anisotropic phase.

$\frac{d\mu}{dt} = 3.27$, to 1.53 erg/deg. Isotropic phase.

(The fourth substance showed a decrease up to a certain point, followed by gradual increase. This is due probably to a second anisotropic phase.)

[36] *Ann. d. Phys.*, **2**, 676, 1900. Substances used with a trace of oil, peperin, etc. p. azoxyanisole, p. azoxyphenetole, anisaldazine.

[37] BOSE: *Phys. Zeit.*, **10**, 241, 1909; **12**, 60, 1911. Ch. Manguin, *Comph. Rendus*, **152**, 1680, 1911, etc.

[34] *Zeit. f. Elektro. Chem.*, 16, 702, 1910. See also *Theor. Chem. Tauf.*, 3666. Cf. v. WARTENBERG: *Phys. Zeit.*, 12, 837, 1911. Wartenberg, in spite of the fact that he rejects Lehmann's theory, had to admit that this phenomenon does not furnish any evidence against Lehmann's theory.

[35] *Phys. Zeit.*, 14, 646, 1913. Substances: p. azoxyanisole, p. azoxyphenetole, and anisaldazine.

[36] Dissertation, DANZIG: When the diameter of the tube is comparable with the magnitude of the swarms the efflux ought to be comparatively slower than when it is large in comparison with the size of the swarms. The flow ought to be slower for small capillaries than that given by Poiseuille's equation.

$\frac{P\pi TR^4}{8L\eta}$ = volume discharged in time T under a pressure P, in a tube of radius R, and length L when η is the viscosity of the liquid at a given temperature.

[37] *Phys. Zeit.*, 8, 42, 1907, etc.

[38] *E.g., Biochem. Zeit.*, 63, 1, 74, 1914.

[39] *Ann. d. Phys.*, 39, 80, 1912.

[40] *Phys. Zeit.*, 14, 1129, 1913.

[41] *E.g., Phys. Zeit.*, 14, 2, 1913.

[42] Molekular theorien, Vol. 2, page 413, 1889. Flüssige Kristalle, 164, 1904.

[43] See Verzeichnis sämtlicher Veröffentlichungen von O. Lehmann. Fr. Vieweg and Sohn. Braunschweig.

[44] See (25) *Theo. Chem.*, 7 Ed., 666.

[45] Method of Manguin, *Phys. Zeit.*, 12, 1013, 1911. Hot sulphuric acid and subsequently washed in ether and distilled water.

[46] Neufeld's work showed conclusively that the pressure-velocity variation in the Poiseuille state of flow remains constant for different sized capillary tubes. This is in accordance with Lehmann's conception of lamellar anisotropic molecules, but it is not in accordance with Bose's "swarms" unless these swarms are of molecular dimensions or very much smaller than Bose's estimate.

[47] *Phys. Zeit.*, 15, 141, 1914.

[48] *Zeit. Phys. Chem.*, 61, 166, 1907; *Acta Nova*, 90, 1909. C.f. *Phys. Zeit.*, 11, 177, 1910.

[49] Vorländer: "Flüssige Kristalle," p. 22; *Zeit. Chem.*, 57, 363, 1906.

[50] *Bull. Soc. France Min*, 33, 192, 409, 466, 1910. *Compt. Rendus*, 151, 442, 1910.

[51] For development see von Laue, "Festschrift der Dozenten," Zurich, 1913, and Bragg, "X-rays and Crystal Structures," 2d Ed.

[52] T. TERADA: *Tokyo Math.-Phys. Soc.*, 7, 60, 1913, for visual shift of points due to a rotation of the crystal.

[53] The incident rays are in all cases supposed to pass through a circular diaphragm.

[54] *E.g.*, LAUE: "Festschrift d. Dozenten," Zurich.

[55] FRIEDRICH: *Phys. Zeit.*, 14, 1079, 1913. M. v. LAUE and J. STEPH. v. D. LINGEN: *Die nat. Wissensch.*, 13, 1914. In the case of burcite the author has shown that this phenomenon is due to driving off water molecules, and that the crystal then behaves as if the C' axis becomes elongated. On account of the fact that C' is not constant for crystals, the points proceed and

recede—from layer to layer—from the central spot so that the radial line gives the intensity of the spectrum.

[47] See *Phys. Zeit.*, 14, 1079, 1913. *Tokyo Math.-Phys. Soc.*, 7, 60, 1913.

[48] *E.g.*, HUPKA: *Phys. Zeit.*, 14, 623, 1913. O. LEHMANN: *Ann. d. Phys.*, 2, 676, 1900, etc.

[49] E. BOSE: *Phys. Zeit.*, 12, 60, 1911. A. v. WARTENBERG: *Phys. Zeit.*, 12, 837, 1911, etc., etc.

[50] Dissertation, Göttingen; or, *Ann. d. Phys.*, 37, 397, 1912.

[51] The flat pieces of rubber have this advantage, that they distribute the pressure evenly over the glass plates; moreover, their thickness could be regulated better than those of the ring.

[52] "Molekulare Bau Flüssiger Kristalle," 1913. Subsequent experiments with crystals mounted on glass showed that this effect is not given by glass plates.

[53] *Verh. d. Deutsch Phys. Ges.*, 18/19, 1913.

Double Refraction and Crystalline Structure of Silica Glass. LORD RAYLEIGH. (*Proc. Royal Society*, No. A. 692.)—Ordinary glass is not doubly refracting except when under stress. In contradistinction to this the experimenter found that silica glass, produced by the melting of clear, cyrstalline quartz, does have double refraction, though it is only to the extent of one-sixtieth of that of crystalline quartz. When examined by nicol prisms the glass shows a granular structure, possibly due to the pieces of silica melted together to form the piece under examination. Optical silica, built up by a special process, presented, when placed between crossed nicols, an appearance resembling the interference figure of a uniaxial crystal in convergent light. Specimens of this glass were heated to red heat over a period of two hours and were then quenched in water. Contrary to expectation, a network of cracks appeared on the surface. After the surface had been repolished examination with the nicols showed no trace of the former pattern. Reheating for ten minutes caused the reappearance of pattern.

G. F. S.

Combined Developing and Fixing. (*Photographic Jour. of America*, March, 1921, p. 124.)—French photographers seem to be especially interested in bizarre processes, and among these have investigated the methods by which the developing and fixing agents are combined in one solution. They have also given attention to processes in which fixation precedes development, a curious and interesting reversal of the usual method, and one that has been but little considered by the writers on the latent image. Lumière Brothers and Seyewetz have been especially active in researches along this line, and in a recent communication to the French Society of Photography

(*Bull. Soc. Franc. d. Phot.*, November, 1920, reprinted in *Photo-Revue*, 1921, 5) give some new methods for using combined baths. After a review of the literature and pointing out some unsatisfactory methods, they give two solutions which they claim will give good results. These are:

FORMULA NO. 1.

Water	1000 c.c.
Sodium sulphite	32 grm.
Chloranol	6 grm.
Sodium hydroxide	5 grm.
Hypo	60 grm.

FORMULA NO. 2.

Water	1000 c.c.
Sodium sulphite	32 grm.
Metoquinone	6 grm.
Tribasic sodium phosphate	100 grm.
Hypo	40 grm.

The sodium sulphite is the ordinary anhydrous form. The sodium phosphate is the one in which all the hydrogen of the acid is replaced, being Na_3PO_4, and not the common form sold in drug stores. In formula No. 1 the sodium hydroxide can be replaced by 140 grm. of the tribasic phosphate and the hypo reduced to 48 grm.

The writers claim that these formulæ will give negatives of entirely satisfactory character, and are especially applicable to cases of over-exposure. The duration of the process is from twenty to twenty-five minutes and is automatic, taking place equally well with vertical or horizontal position of the plate. Papers require only about two minutes. They also claim that the procedure does not require a special method of illuminating the room in which the operation is conducted. A greater or less duration of the process does not imperil the value of the negative.

Metoquinone is stated to be composed of two molecular weights of methyl-paraminophenol and one molecular weight of hydroquinone; chloranol is composed of two molecular weights of methyl-paraminophenol and one molecular weight of chlorhydroquinone. Both these substances share with paraminophenol the property of developing without the addition of alkali, but alkali may be added as accelerator.

With chlorbromid papers it is advisable to double the time of exposure, and the action of the bath should not be continued beyond two minutes or the purity of the image will be diminished. Papers containing only silver bromide cannot be developed by these methods, as they become markedly veiled. The addition of potassium bromide does not prevent this action.

A NEW GENERAL LAW OF DEFORMATION.*

BY

P. G. NUTTING, Ph.D.

THROUGHOUT the mechanics of elasticity and hydrodynamics frequent use is made of the laws:

I. DEFORMATION PROPORTIONAL TO FORCE APPLIED,

and

II. RATE OF DEFORMATION PROPORTIONAL TO FORCE.

The first of these applies to elastic bodies and is commonly known as Hooke's Law, the second is used in dealing with fluid flow and lacks a specific name though the particular form relating to flow through small tubes is known as Poiseuille's Law.

Hooke's Law is known to hold closely over a considerable range of forces for many solids. Failing to take account of either plastic or viscous yield or any other form of energy dissipation, it applies best to the more nearly perfectly elastic bodies. The viscosity law (II) applies fairly well to many fluids, both highly and but slightly viscous, but not at all well to others. It assumes complete dissipation of the work done in deformation with no elastic storage of energy. Both laws are empirical approximations and must remain so unless they can be deduced from known molecular relations. If one may judge from the literature of the subject, experimentalists have rested in the belief that theoretical work had established the foundation for these laws, while theoretical writers, on the evidence of the experimentalists, have contented themselves with the first term of a Taylor series expansion of an unknown function. Voigt frankly states (Mechanik, 1901, pp. 474 and 495) that the ultimate causes of both elasticity and viscosity are molecular and that the linear relations given rest on the pure assumption that the second order terms are negligible.

In mathematical form, the two laws mentioned, namely:

(1) $$s = kF$$

and

(2) $$s = ktF$$
$$v = ds/dt = kF$$

are at first sight incompatible as applied to the same material. If

* Communicated by the Author.

a steady stress produces a continuous deformation (2) in a homogeneous body, that body cannot possess elastic properties toward the same steady stress and conversely if a body is elastic (1), it is incapable of steady flow. On this basis only heterogeneous bodies are therefore capable of both elastic and viscous deformation under a given stress. The accepted electromagnetic theory of light is based on the assumption of displacements of this nature.

Michelson [1] has carefully investigated the yielding of metals and other solids under a torsional shearing stress. In formulating his results he writes for the displacement the sum of four components: (1) lost motion, (2) elastic, (3) elastico-viscous and (4) viscous displacement. The complete expression is extremely complex and involves nine constants. The term representing the "elastico-viscous" displacement (No. 3) is

$$s_3 = c_3 \left(1 - e^{-a\sqrt{t}}\right) FebF \tag{3}$$

This does not represent our data as well as the much simpler formula given below.

In order to obtain precise data upon which to formulate a law applicable to slowly yielding media, the writer took up the study of deformation in pitchlike substances subjected to pure coplanar shearing stresses. Many such substances are known to possess both elastic and viscous properties in a high degree and it was hoped that the data obtained might throw light on the fundamental principles upon which (I) and (II) are based. The results indicate that each is a special case of a simple general law, a law quite new in mechanics and of extremely wide application. It is empirical, but so are the laws of elasticity and of viscous flow just mentioned. Carrying the analogy over into electrical theory, another general law of electrical conduction is obtained of which Ohm's Law is a special case.

Considerable data by many observers is available for testing deformation formulas. That obtained by the writer is being presented at the 1921 meeting of the American Society for Testing Materials with complete descriptions of instruments and methods employed which need not be repeated here. Suffice it to state that the shear measured was produced between parallel plates 50 x 100 mm. in area, 2 mm. apart. Displacement readings were taken after ten

[1] A. A. Michelson, *Proc. Nat. Acad.*, May, 1917, and March, 1920.

or more time intervals after each force was applied, and for six to ten different forces and usually several different temperatures. One substance was found (a hard stearine pitch) for which the viscosity as ordinarily computed decreased to one-tenth as the force was increased from 1 to 10 kg. Another, although a hard solid (140° hydrolene), showed true viscosity, *i.e.*, the ratio of force per unit area to rate of shear was practically independent of the force applied.

The displacement-time curves were found to be generalized parabolas, s proportional to the n^{th} power of the time t, hence $log\ s$ a linear function of $log\ t$. Further, n is the same for all forces, the various s–t curves differing only by a constant factor. A similar relation was found to hold in all cases for the displacement-force curves (time constant), $log\ s$ is a linear function $log\ F$, s being proportional to the m^{th} power of the force F for any constant time without systematic variation.

Our general formula is then

$$s = at^n F^m \tag{4}$$

in which n and m are independent of s, t and F but are functions of the temperature. They are also, of course, independent of the area and thickness of the test piece, independent of the units employed, and also of the method of test so long as it involves only a pure shear. The constant a is independent of s, t and F but depends on the units and method employed.

It is readily seen that the old law of elastic deformation (I) is a special case of (4) for which $n = 0$ and $m = 1$. Also the law of viscous deformation (II) $s = atF$, or $v = aF$ is a special case for which $m = 1$ and $n = 1$. Experimental values of n have been found as low as 0.2 and as high as 0.91 and of m from 0.74 to 3.5. A value of m greater than unity means a plastic yield more than proportional to the force, often of the nature of an internal rupture, while a value less than unity signifies the converse, a consistency resembling quicksand in its nature. All highly fluid liquids of course have n nearly unity, in fact melting might be defined as a temperature at which n has a definite assigned value approaching unity. Similarly a definite low value of n approaching zero might be used to specify the beginning of the solid state.

Alternative forms of the general deformation law (4) may be written

$$\frac{ds}{s} = n\frac{dt}{t} + m\frac{dF}{F} \tag{5}$$

$$s\left(\frac{t}{s}\frac{ds}{dt}\right)^n = (an)^n F^m \tag{6}$$

From (5) it is evident that the error in theoretical work on deformation has been the neglect of large second order and time effects not really negligible. Experimental work has been in error through the assumption that deformation is proportional to the force producing it. From (4) and (5) it is evident that a more general form of statement of (I) and (II), including both is

III. PERCENTAGE DEFORMATION IS PROPORTIONAL TO PERCENTAGE CHANGE IN THE FORCE, OR
LOG DEFORMATION IS A LINEAR FUNCTION OF THE LOG OF THE FORCE PRODUCING IT.

However, time must be considered and must be the same for any two or more cases under comparison. Equation (6) is obtained by eliminating t from (4) and its time derivative. It indicates that the quantity $(an)^{-n}$ is a sort of generalized viscosity.

Since the general law of deformation must depend in some manner upon the strain and rupture of molecular bonds, the relaxation from a strained condition is of considerable theoretical interest. Relaxations amounting to half the original shear and continuing for ten minutes were observed in some pitches. The initial portion of the relaxation-time curve is almost identical with the initial part of the displacement-time curve preceding it. The relaxation function is of the same form as the deformation function (4), F being interpreted as the force just previously active. Our data on four widely different pitches indicate that for relaxation the constant m is the same, but a and n different, usually much less than for the preceding deformation. Thus for hard stearine pitch,

$$s = 0.28\, t^{0.56} F^{2.0}$$

$$R = 0.24\, t^{0.33} F^{2.0}$$

In relaxation, as in deformation, the time exponent is independent of the force that has been acting and the force exponent is independent of the time.

Another property of strained materials of great theoretical significance is the automatic release of internal strain with time if simply held in a fixed strained position. This property is associated with and complementary to the relaxation in form mentioned in the last paragraph. Deformed crystals tend to reform in an unstrained condition. Permanently deformed springs weaken gradually with time. We have seen springs of ferrous alloy receive a large permanent set on annealing at only 150° C. when in a strained condition. Amorphous bodies such as pitch, when deformed may be regarded as anisotropic but gradually return to an isotropic condition after a gradual molecular rearrangement requiring some minutes. In solids that rearrangement is much slower, in liquids much more rapid and in gases practically instantaneous. Since rate of deformation $ds/dt = ns/t$ is proportional to deformation s, a rupture theory is indicated in which the (molecular) rupture is self healing at a uniform rate.

The agreement of (4) with data by other observers obtained by other methods is of interest. Data by Green (A. S. T. M., 1919) relate to paints forced through capillary tubes by various static pressures of wide range. Taking his values for rate of discharge as a function of pressure for paints composed of linseed oil mixed with varying proportions of zinc oxide, the constant m in (4) was found to be 3.5 and the same not only for all pressures but for paints ranging from moderately thin mixtures to a thick paste. Data for computing n were not given, although a time effect attributed to inertia was noted. Data taken on an insulating oil with a MacMichael viscosimeter in this laboratory gave a value of $m = 0.77$, again without systematic variation. In this case F is the torque produced by a rotating cup of fluid on a disk suspended in it, and ds/dt is the angular velocity of the cup. Viscosity computed in the ordinary way varied by a factor greater than 2 as the velocity was varied from 1 to 30 R. P. M. This and other forms of absolute viscosimeter have been discredited because they indicated a variation of viscosity with velocity. It appears that the assumption, not the instrument, is in error. Time effects in the strain of elastic solids have been noted by many observers, but no precise data can be found for testing the formula.

The current through some leaky dielectrics attains a steady value only after several seconds or even many minutes from the time a steady E. M. F. is applied. This retardation is difficult to

account for on the basis of any accepted theory of conduction; induction effects are not involved, and both displacement and Ohm's Law currents reach a steady value in a minute fraction of a second. Polarization, caused by an accumulation of ions, can be effective only near the electrodes while the effect of secondary ionization by collision is to increase rather than to decrease the current with time.

The mathematical theory of such conduction is similar in form to that applicable to deformable bodies, but the relation of this mechanical law to the electrical case under consideration is not merely a formal one. The electrical displacement consists of motions of electric charges impelled by potential gradients and if these charges are carried by material particles, the motions of the charges will be governed by the motions of the particles with which they are associated, the impelling force being electrical instead of mechanical. Corresponding with mechanical strain or displacement s in the above formulas, is q the electrical displacement; current density $i = dq/dt$, corresponds to ds/dt while potential gradient X corresponds to stress F in the mechanical equations. The tentative forms for electrical displacements are therefore

$$q = at^n X^m$$
$$i = ant^{n-1} X^m$$
$$di/dX = anmt^{n-1} X^{m-1}$$

Ohm's Law is a special form for which both m and $n=1$ corresponding to pure viscosity in fluid motion. The special case of $m=1$ and $n=0$ is that of purely elastic displacements in ideal dielectrics.

The value of the new form lies in its flexibility and generality. Note that both q and i are *additive* ($q = q_1 + q_2 +$), being in general sums of terms of the same form but with different constants. Consider the case of leakage through mica. The current even after 30 minutes (7.10^{-13}) was still twice as great as after an hour and $^1/_3$ the value after 5 minutes. An elastic displacement current ($i = dq/dt$) would have come to zero in a fraction of a second. Adding a conduction current $(E-P)/R$ such that

$$i = \frac{dq}{dt} + \frac{E-P}{R}$$

does not represent the facts any better since the current does not drop suddenly to a steady value but decreases very gradually for a long time. The new formula represents this decay curve for mica very well if n is small and negative but not zero ($n = -0.2$).

Mr. J. E. Shrader has studied the variation of current with voltage and with time. The only material for which both are reported is xylene. For this liquid the equations

$$q = 3.7 \times 10^{-13} t^{0.88} X^{1.38}$$
$$i = 1.23 \times 10^{-13} t^{-0.07} X^{1.38}$$

have been deduced. For illustration, other rough values may be mentioned: varnished cambric $m = 0.70$, fuller board $m = 0.73$, cement paper $m = 0.54$. For castor oil $n = 1.0$, high flash oil $n = 0.23$, bakelite test cup $n = 0.74$, white India mica $n = -0.2$.

Both theory and experimental data indicate that the best technical dielectrics are those for which $n = 0$ or the smallest possible with m nearly unity and a very small over the range of operating temperatures. The watt loss per cycle of course depends directly upon n since it is a time integral over a cycle and approaches zero as n approaches zero. The possibility of establishing technical criteria of quality appears worth following up.

PITTSBURGH,
March, 1921.

The Common Occurrence of Aurora in the South of England. LORD RAYLEIGH. (*Nature,* March 31, 1921.)—There is a certain green line of wave-length 5578 Angstrom units, which is found in the light of the aurora. Several observers have noted that this line is of common occurrence in the light of the sky at night. Two years ago Slipher identified it at the Lowell Observatory, Cal., on every clear night on which he sought for it. Lord Rayleigh has renewed his quest for this line in England and has found it on many nights. It is, however, not always obtainable. One "fairly clear" night it was absent, while it appeared on many cloudy nights. He attributes his success to the use of Marion's "iso-record" plates especially sensitive in the green region of the spectrum. The experimenter proposes a program of "systematic comparison of the auroral intensity with sun-spots and magnetic disturbances, and also a comparison of its different intensities in Great Britain and elsewhere."

G. F. S.

The output of solid mineral fuel in France for November, 1920, was 2374 thousands of tons as against a monthly average in the year before the war of 3404. From January to December of last year the number of mine workers rose from 188,000 to 224,000. The deficiency of coal was supplied in order of decreasing importance by Great Britain, Germany, the Sarre Basin, the United States, and Belgium. (*La Nature,* April 2, 1921.)

G. F. S.

Paper as Substitute for Glass. (*Photographic Jour. of America*, February, 1921, p. 82.)—Paper negatives are not new. The older photographers remember them well, but like coffee, dry-plates, tin-types, and many other expedients in photography, they have been relegated to the limbo of forgotten things. Lately, however, owing to the very high cost of glass in Germany, two prominent German firms have placed on sale a special form of paper negative. The *Photographische Rundschau* describes the product, and the issue carries two advertisements of it. The Farbenfabriken Friedr. Bayer & Co. advertise under the trade name of "Plattenfort", a negative paper, orthochromatic and highly sensitive, suitable for landscape and instantaneous work. Metallic frames, enameled with black, are provided as supports for the negative and fit in the ordinary dark slide. Exposure and development are made as with glass negatives. Owing to the opacity of the paper, the degree of development is not so easily judged as with glass, but it is claimed that this difficulty is soon overcome by experience. Development usually takes about five minutes. After fixing, washing and drying, the film is removed from the paper. The attachment of the film to the paper is made in such a way that simply pulling up one corner enables the whole extent to be drawn off, the operation being materially aided by the fact that the film, which is of gelatin, is fairly firm, and if fixed in an alum bath, is further hardened. The film can be used then as a negative. One advantage over glass negatives is that in pigment printing, such as carbon work, the film can be reversed, thus avoiding the duplicate treatment that is usual.

The other factory furnishes a plate of somewhat similar character, but the separation of the gelatin from the paper support is accomplished by cutting a bevel along the edges, so that the film extends a little beyond the paper base, when it can be easily removed. The advertisement of the first-mentioned firm claims the new form as "light, unbreakable, free from halation and capable of being copied from either side," in addition to being orthochromatic and very sensitive.

Selenium a Rare Element. (*U. S. Geological Survey Press Bulletin, No. 469*, April, 1921.)—Selenium is a rare and little-used element described by the Survey as having its greatest use in giving a red color to glass, such as that used on railroads for signal lights, and in coloring enameled ware red. It is also used to overcome the natural green color of ordinary glass. Selenium is peculiar in being a very poor conductor of electricity in the dark and a fairly good conductor in the light and is used in several electrical devices whose utility depends on this peculiarity. It has been used in telephoning along a ray of light and in transmitting sounds and photographs from one place to another over a wire.

GROUND-PLANE INFLUENCE ON AIRPLANE WINGS.*

BY

A. F. ZAHM, Ph.D., and R. M. BEAR, B.S.

Bureau of Construction and Repair, U. S. N.

Preface.—As the air action on the wings of an airplane may change materially, for a given speed and poise, when the craft leaves or approaches the earth's surface, the nature of this change has been deemed worth investigating with a model in the wind tunnel. A test made on a single British R.A.F. 6 aerofoil at 40 miles an hour in the 4′ x 4′ tunnel, at the Washington Navy Yard, is described in this article. The model was made of brass and measured 3 x 18 inches; it had the form of profile shown in Fig. 5.

Method of Measurement.—Fig. 1 shows the apparatus for the test assembled in the 4′ x 4′ tunnel. The aerofoil is held as usual at the extremity of the tapering spindle of the cross-arm wind balance, and has at one side a "ground-plane" parallel to the walls of the tunnel and held at its top and bottom edges in two grooved planks as shown. The plane, made of ⅜″ laminated pine, is about two feet wide along stream and chamfered to a thin edge on the side remote from the aerofoil. The guide boards are grooved for a distance of two feet, then chamfered up stream to edges flush with the floor and the ceiling. The grooves are ¼″ wide and spaced ½″ between centres; and each indicates the distance from the nearest face of the plane to the chord of the aerofoil at zero pitch.

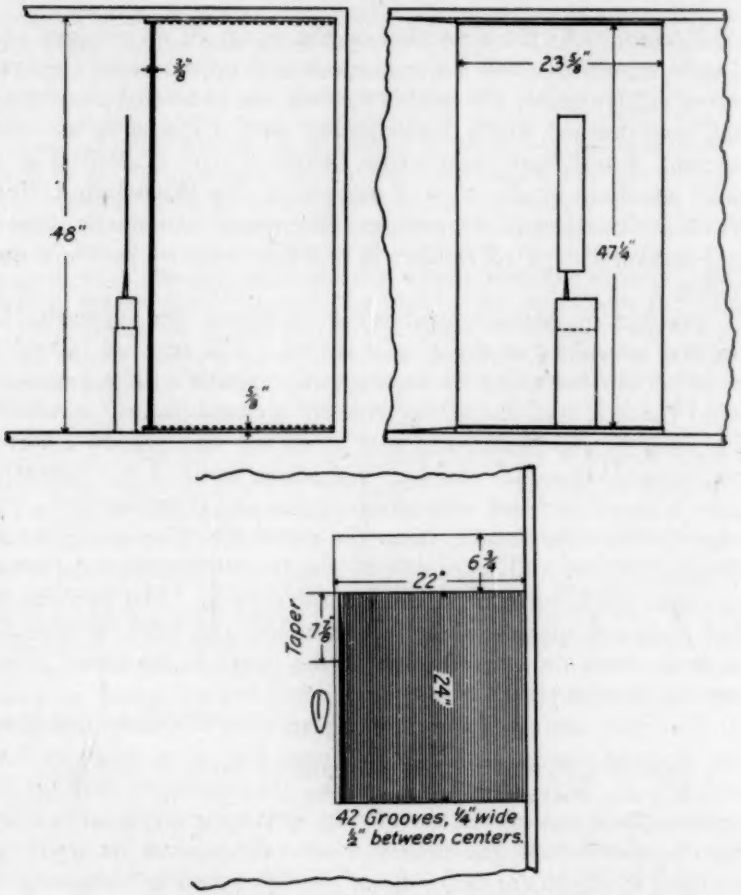
For each setting of the ground-plane, the lift, drag, and pitching moment was measured in the usual way at 40 miles an hour and 0°, 4°, 8°, 12° and 14° pitch. In successive settings the ground-plane was moved laterally, by increasing steps, up to 16½″ then removed from the tunnel or set over against its wall; this farthest displacement being about the equivalent of removing the plane entirely, when allowance was made for the change of cross-section of the tunnel due to such removal.

Values of Lift and Drag.—The measurements of lift and drag are not tabulated but are plotted to ample scale in Figs. 2, 3, 4.

* Communicated by Dr. Zahm.

For all angles of incidence, as should be expected, the graphs of lift, drag, and lift-drag curve less and less rapidly as the ground-plane shifts from about half a chord length successively to greater distances from the aerofoil. They each tend to approach

FIG. 1.



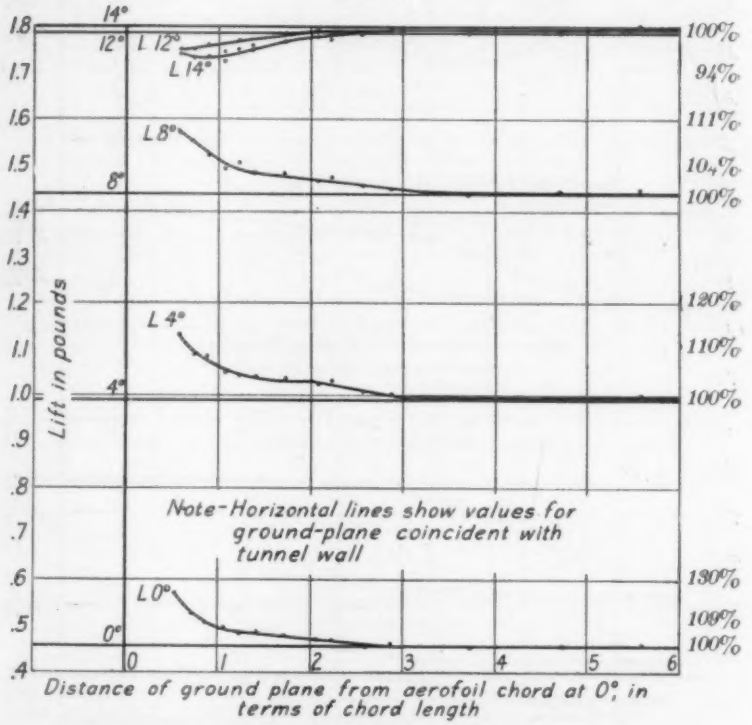
Aerofoil and ground-plane in 4 x 4 foot tunnel.

asymptotically a horizontal line which marks, for the represented quantity, the value obtained with the ground-plane indefinitely distant.

The curves are roughly exponential and may be expressed in

the form $y = a + b\ e^{-cx}$, where a is the asymptotic value, $a + b$ the initial value, x the ground-plane distance, c the coefficient of decay of the ground-plane influence. The dotted lines in Fig. 4 are true exponential curves and coincide with the actual plotted data to within the degree of precision of the measurements. The numeri-

FIG. 2.



Lift *versus* ground-plane distance "*below*" aerofoil. Air speed 40.3 m. p. h.

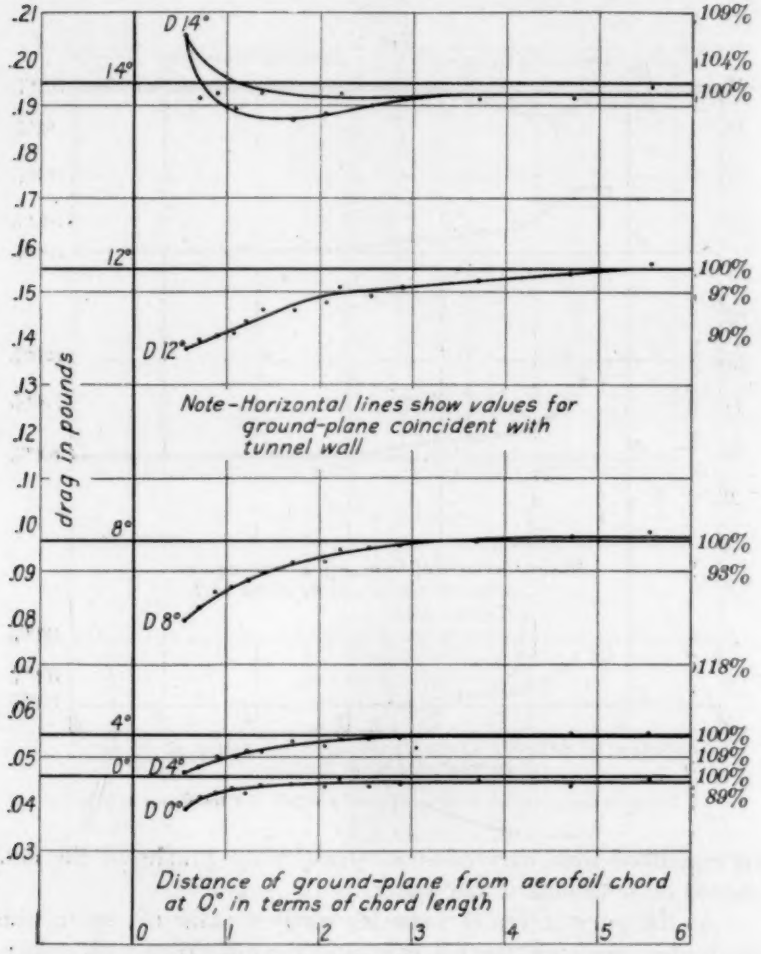
cal equations were derived from straight-line graphs of the data plotted on semi-logarithmic paper.

As the pitch increases from its smallest value 0°, up to near the burble incidence, the lift falls, and the drag rises with enlarging gap between the aerofoil and the ground-plane; also for these conditions the curves are farther separated from their asymptotes initially, and reach practical contact with them farther from the origin. The asymptotes in all cases were hurriedly found from a

single measurement, and in some instances seem to be less trustworthy than the curves approaching them.

As the pitch approaches the burble angle the ground-plane

FIG. 3.



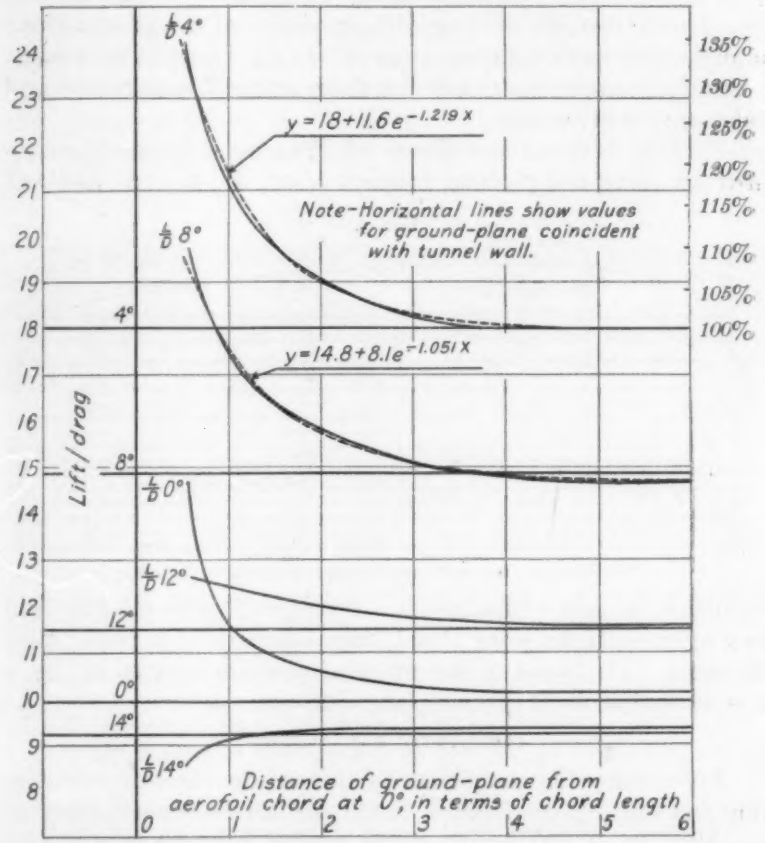
Drag *versus* ground-plane distance "*below*" aerofoil. Air speed 40.3 m. p. h.

effect diminishes roughly to 0, then becomes increasingly negative as far as the test discloses.

The numbers on the right-hand side of Fig. 4, at the top,

indicate that the efficiency of a monoplane wing closely skimming the earth's surface may be increased 20 or 30 per cent. at 4° incidence. A still higher efficiency is indicated by the lift-drag curves for smaller angles of incidence.

FIG. 4.



$\frac{\text{Lift}}{\text{Drag}}$ *versus* ground-plane distance "*below*" aerofoil. Air speed 40.3 m. p. h.

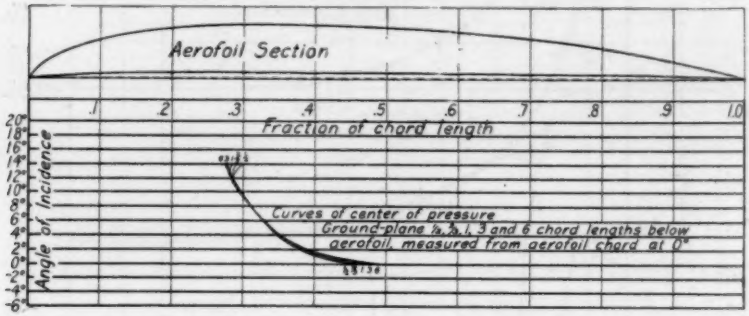
From Figs. 2 and 4 it appears that at small incidences a monoplane is considerably better sustained and more easily propelled near a ground-plane than when two or three chords above it. This fact might be turned to account in navigating above smooth water. It is distinctly marked by the pilot in trying to land at too

high a speed on a flat surface. The airplane tends to rebound as if striking a denser medium.

A complete set of readings also were taken with the ground-plane "above" the aerofoil, that is opposite its more chambered surface. The most striking features of these readings are the great increase of lift with increasing incidences up to 12°, and the considerable increase of drag with proximity of the ground-plane at all the incidences used, *i.e.*, from 0° to 14°. The data were taken rather for completeness than for their practical importance, and hence are not given here.

Pitching Moment and Centre of Pressure.—From the measured lift, drag and pitching moment at 0°, 4°, 8°, 12° and 14°

FIG. 5.



Aerofoil section and centre of pressure. Air speed 40.3 m. p. h.

incidence, the centre of pressure was computed with the gap fixed first at one-half the wing chord, then successively at larger fixed distances. The travel of the centre of pressure is given in Fig. 5 and shows but slight ground-plane influence.

CONCLUDING PARAGRAPHS.

Reference.—On completion of this article the writers' attention was called to an account, in the *Ace* for December, 1920, of a test by Mr. A. A. Merrill, of the ground influence on a biplane model at the single angle of incidence of 13°. He observed at this angle a slight ground effect and shift of the centre of pressure. He concludes: "This experiment then seems to show that the correction for ground effect upon landing is small though not negligible."

Dr. A. Betz reports,[1] for lift and drag only, the ground influ-

[1] Zeitschrift für Flugtechnik und Motorluftschiffahrt, 1912.

ence on a curved zinc plate to be quite similar to that found in the present test of a regular wing form. His model measured 10 x 60 millimetres, and was tested in a tunnel about two metres square in cross-section.

Summary.—The present study discloses a very material ground-plane influence at small incidence and ground gap. The lift is augmented, the drag diminished; the lift-drag may be increased 30 to 40 per cent. Thus a sea gull or a suitably designed monoplane may skim the surface of smooth water with considerably greater economy than it can fly at a few wing depths aloft. But the pitching moment is only slightly affected by the presence of a ground plane.

The Magnetic Mechanical Analysis of Manganese Steel. SIR ROBERT HADFIELD and MESSRS. S. R. WILLIAMS and I. S. BOWEN, Oberlin College. (*Proc. Royal Society*, No. A. 692.)—This is a preliminary attack upon the problem of correlating the magnetic with the mechanical properties of ferromagnetic substances. Two sets of rods were used. They came from the same source but had received different heat treatment. All were heated to 1000° C. and then quenched in water. Half of them were subsequently annealed. Both types were subjected to an increasing magnetic field. The annealed specimen showed an increment of length with every increase of field-strength, while no change of length at all was observable in the case of the unannealed piece (Joule Effect). The effect upon intensity of magnetization produced by stretching rods of the two types was also investigated (Villari Effect). For the annealed rod and application of tension increased the intensity at all field strengths, but for the other rod tension made no difference. It was afterward found that the removal of a few thousandths of an inch of the outer layer of the unannealed rod caused it to cease to show any trace of being a magnetic substance.

"Whether we shall ever be able to interpret all of the mechanical properties of ferromagnetic substances from their magnetic behavior is a question, but from what has been accomplished there are fair promises, and no avenue seems more inviting than the one which has been followed in this study, where the magnetic and mechanical effects are so closely associated. Here is a splendid opportunity for cooperation between the large steel industries with their resources of materials, and the research laboratories with their resources of skilled investigators, to make a very thorough study of this field. X-ray methods, and the methods indicated above, seem to be about all the means we have at present to test the mechanical properties of a substance without injuring the sample tested. There are some advantages in the magnetic method." G. F. S.

Method of Developing Highly Sensitive and Panchromatic Plates by Ordinary Light. (*Photographic Jour. of America,* February, 1921, p. 84.)—Dr. Lüppo-Cramer describes in the Swiss journal, *Die Photographie,* the following method by which plates that are usually developed in special safe-light may be developed without danger of fog in ordinary light. He found, in the course of studies on sensitizing plates, that the safranin dyes possess the property of diminishing sensibility of silver bromide in a remarkable degree. If to one of the ordinary developers a very dilute solution of phenosafranin (1 to 2000) is added in the proportion of 10 c.c. of the color solution to 100 c.c. of the developer, and the plate allowed to remain for about a minute in the mixture, the development may be then continued in bright yellow light. The plate can be lifted out of the liquid in order to examine the condition of the image; inasmuch as the action of the color is not merely that of a protecting screen, but a deep chemical or physical change in the silver bromide. Lüppo-Cramer states that it is possible to conduct the development in such a way that a special darkroom illumination is not needed. The plate is immersed in total darkness in the color solution for about a minute, and then placed in the developer. Just before this transfer, a stearin candle, placed at a distance of six feet from the plate, is lighted. In this convenient illumination the development of even very sensitive panchromatic plates may be carried out without any danger of fog. Even the liability to chemical fog on the part of the plates sensitized with isocyanin is avoided by the method.

Electric Power Production. (*U. S. Geological Survey Press Bulletin, No. 469,* April, 1921.)—The total production of electric power by public-utility companies in 1919 was 39 billion kilowatt-hours, according to the Survey. Of this power 62 per cent. was produced by fuels—35 million tons of coal, 11 million barrels of oil, and 21.7 billion cubic feet of gas—the remainder by water power.

The Photo-Electric Theory of Vision. J. H. J. POOLE. (*Phil. Mag.,* March, 1921.)—In an address to the British Association in 1919 Sir Oliver Lodge made the suggestion that the sensation of vision might be due to effect of photo-electrons emitted by some substance of the eye under the stimulus of the incident light. It is known that metals emit negative electrons when illuminated under suitable conditions. A careful examination of the black pigment and of the visual purple of the eye was made, but no evidence was secured that they emit electrons. There is therefore no experimental evidence for this attractive and picturesque theory.

G.F.S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

NICKEL.[1]

[ABSTRACT.]

THE larger part of the world's production of nickel comes from the famous pyrrhotite-chalcopyrite ores of the Sudbury district in Canada. These ores are at present smelted and refined by three processes, the larger tonnage being smelted in Canada and refined both there and in the United States by the Oxford Process. A natural alloy, Monel Metal, is produced from the same ores by roasting and reducing the copper-nickel matter shipped to New Jersey from the Canadian Smelters.

FORM AND USES.

Nickel is produced in the United States in several commercial forms. The greater tonnage is produced in the form of 50- or 25-lb. *ingots,* or *pigs,* which are used in the manufacture of nickel-bearing alloy steels. *Nickel shot* and *electrolytic nickel cathodes* are produced for the use of the manufacturers of non-ferrous nickel alloys, nickel-silver and cupro-nickel. Malleable nickel—sheet, strip, rod, wire—is produced for stampings, fittings, resistance and pyrometer wire, spark-plug points, and kitchen utensils. Nickel castings are produced for the chemical industries for use against corrosive solutions. Nickel is generally useful by reason of its anti-corrosive properties.

Monel metal is produced in the usual commercial forms, *i.e.*, castings, rods, sheet, wire, and is principally valuable because of its resistance to corrosion, its high strength at higher temperatures, and its resistance to the erosive action of superheated steam (use in turbines and steam valves).

Data relating to chemical composition and physical properties of pure and commercial nickel and of Monel metal are also given in the complete paper.

ALLOYS OF NICKEL.

Besides the nickel, or nickel-chromium alloy steels containing

* Communicated by the Director.

[1] Circular No. 100.

from 1–3.5 per cent. nickel and largely used for automobile and ordnance construction, there is a large number of other nickel-bearing alloys having very interesting and commercially useful properties.

Nickel-silver, containing from 52–80 per cent. of copper, 10–35 per cent. of zinc, and 5–30 per cent. of nickel, is used in sheet form for the base metal for silverplated household ware and other stampings and fittings, in the wire form for resistance wire, and in the cast form for automobile hubs, etc.

Cupro-nickel, containing about 15 per cent. of nickel, balance copper, is used for the manufacture of small arms bullet jackets.

Constantan, containing about 45 per cent. nickel, balance copper, is used largely for resistance and pyrometer wire.

Ferro-nickel, or 25–35 per cent. nickel-steel is used as resistance wire and as *Invar* having a low coefficient of thermal expansion.

Nichrome, and similar alloys, containing from 60–80 per cent. of nickel, together with chromium and iron, is used for resistance wire and as a heat or temperature resisting alloy.

Manganese-nickel alloys, containing from 2–4 per cent. of manganese and the balance nickel, are used largely for the manufacture of gasoline engine ignition points, or spark plugs.

RECOMMENDED SPECIFICATION FOR FLAT INTERIOR LITHOPONE PAINT—WHITE AND LIGHT TINTS.[3]

[ABSTRACT.]

THE specification was prepared and recommended by the U. S. Interdepartmental Committee on Paint Specification Standardization. Representatives of paint manufacturers were called upon for suggestions and these were carefully considered in preparing the final draft.

The topics covered include the pigment, the liquid, the paint, methods of sampling and laboratory examination, the analysis of the pigment, and the preparation of the reagents. The laboratory examination covers the caking in the container, the color, weight per gallon, brushing properties, fastness to light, the water content, volatile thinner, the pigment, and the non-volatile vehicle.

The analysis of the pigment includes the qualitative analysis

[3] Circular No. 111.

of water-soluble material, barium sulphate and siliceous material, zinc oxide, and calculations.

The specification is not intended to apply to paints for outside exposure, but requires that such paints shall dry to dead flat opaque coats, adhering well to wood, metal, and plaster, and stand washing with soap and water, and show no material change in color on exposure to light.

THERMAL EXPANSION OF COPPER AND ITS IMPORTANT INDUSTRIAL ALLOYS.[2]

By Peter Hidnert.

[ABSTRACT.]

DATA on the thermal expansion of 128 samples of copper and its important alloys of various compositions, heat treatments, mechanical treatments, etc., are presented. The specimens contained from 56 to 100 per cent. copper and were prepared in a number of ways—cast, cast and cold rolled, extruded, extruded and cold worked, hot rolled and cold worked. Most of the samples were examined from room temperature to about 300° C. (Several specimens were cooled to −50° C. and then heated to + 300° C.)

Practically all available information on the thermal expansion of copper and its alloys is briefly reviewed.

A description of the apparatus and of the preparation of the samples, etc., is given.

Definite mathematical relations were found to exist between the coefficients of expansion and the copper content of most of the alloys investigated (Series II, III, V, VI). In general, the coefficient of expansion increases with a decrease in the copper content. The addition of lead or tin has a decided effect on the coefficient; the former element generally decreases, and the latter increases the coefficient.

Cast and Cold-rolled Copper-zinc Alloys (Series II and III).—In the case of alloys containing 62 per cent. copper it was found that the coefficients did not materially differ in cast or cold-rolled specimens, and for alloys, containing 90 per cent. copper, a similar agreement existed. For alloys with a copper content from about 62 to 90 per cent. the cold-rolled alloys have greater coefficients than the castings, and for alloys containing more than 90 per cent.

[2]Scientific Paper No. 410.

copper the reverse is true. The coefficients of the inside sections of the castings are generally slightly less than those of the outside sections. A relation exists between the density and thermal expansion of the cold-rolled copper-zinc alloys (Series II).

Cast and Cold-rolled Copper-tin Alloys (Series V and VI).—The coefficients of the cold-rolled tin alloys are less than those of the castings. Cold rolling and drawing, therefore, cause a diminution in the values of the coefficients.

Hot Rolled and Extruded Samples (Series I, IV, and VI).—Owing to the large number of varying elements in the hot-rolled and extruded samples, it was impossible to determine the exact effect of each constituent element. In general, however, the coefficients are greater than the extrapolated values obtained from the quadratic equations of the copper-zinc alloys (Series II and III), showing a tendency toward increasing values as impurities are added.

The differences between the various series of samples are discussed in the section "Comparison of Results" and presented graphically in Figs. 39 to 43.

METHOD FOR DIFFERENTIATING AND ESTIMATING UNBLEACHED SULPHITE AND SULPHATE PULPS IN PAPER.[4]

By R. E. Lofton and M. F. Merritt.

[ABSTRACT.]

THIS paper discusses briefly the two possible bases on which to develop methods of differentiating between unbleached sulphite and sulphate pulps, viz.: (1) the different chemical natures of the two pulps due to different cooking treatments, and (2) the different amounts of ligneous matter that may be retained by the two pulps.

The methods followed by other investigators who have studied this problem are given, together with a brief critical commentary on each method. The methods reviewed include: Those used by Paul Klemm, one of whose methods consists in staining with malachite green alone and subsequently examining the color reaction under the microscope, and the second of whose methods consists in staining the fibres with malachite green and then with rosaniline

[4] Technologic Paper No. 189.

sulphate; those used by C. G. Schwalbe, which consist, in one case, in treating the fibres first with a 0.05 *N* aqueous solution of ferric chloride, then with a weak solution of potassium ferrocyanide, and, in the other case, in first treating the fibres with a solution of copper sulphate and following this by treating with a solution of benzo-purpurine 10B; and those used by R. W. Fannon in applying the rosaniline sulphate and sulphuric acid stain and observing the color reactions, in one case with the unaided eye, and in the other case under the microscope.

A discussion of the chemical nature of rosaniline sulphate and of basic fuchsine, one of the dyes used in the method proposed below, shows that these two dyes are essentially alike, but that the latter is to be preferred for this purpose because of its greater solubility.

A few of the more interesting experiments with stains used in developing the method described below are given.

The method recommended by the authors for differentiating between unbleached sulphite and sulphate fibres follows.

The stain used is made by compounding equal volumes—one or two cm.^{3} of each is usually sufficient—of *A* and *B*, made as follows:

A—Malachite green	2 grams
Distilled water	100 cm^3
B—Basic fuchsine	1 gram
Distilled water	100 cm^3

Each new solution made up should be carefully tried out and adjusted for pulp samples of known composition.

The fibrous material is thoroughly disintegrated by boiling a small portion for a few seconds in a ½ per cent. aqueous solution of caustic soda and then shaking in a test tube with water. A few of the fibres are then placed on an ordinary microscope slide and dried with hard filter paper. Two or three drops of the compound stain are then placed on the fibres and allowed to act for two minutes, during which time the fibres are being teased about on the slide by means of teasing needles. The excess stain is then blotted up and the fibres rinsed once or twice with a few drops of a solution of 1 cm.^{3} of ordinary concentrated hydrochloric acid (sp. gr. 1.19) in 1000 cm.^{3} distilled water. This rinsing process is accompanied by teasing the fibres about in the liquid, and should not be continued for more than 30 seconds, otherwise too much stain may be taken from the fibres. The acid solution

is then removed with filter paper and a drop or two of clear water applied and a cover glass placed over the fibres, which are then ready for examination under the microscope. Unbleached sulphite fibres are colored purple or lavender, and sulphate fibres are colored blue to bluish green. If the sulphite or sulphate fibres do not show their proper colorings, a few drops of *A* or *B* must be added to correct the one-sided action of the stain. When the stain functions properly on known pulps it is then ready for use on unknown samples.

The paper also contains tables showing the possibilities of making quantitative determinations of the percentages of these fibres in various mixtures of the two pulps.

"BLACK NICKEL" PLATING SOLUTIONS.[1]

By George B. Hogaboom, T. F. Slattery and L. B. Ham.

[ABSTRACT.]

NUMEROUS formulas have been proposed for the production of "black nickel" deposits such as are used extensively for producing a dark or black finish upon brass or other metals. Two types of solutions have been used, namely, the alkaline cyanide solutions and the neutral sulphocyanate solutions. Experiments showed that the former were very difficult to prepare and maintain of uniform composition, and therefore they cannot be recommended. It was found that a sulphocyanate solution having the following composition proved satisfactory:

	oz./gal.	g/l
Nickel ammonium sulphate	8	60
Zinc sulphate	1	7½
Sodium sulphocyanate	2	15

It is desirable to keep in suspension an excess of zinc carbonate, which maintains the neutrality and the zinc content of the solution.

"Black nickel" plating may be applied successfully to brass, either directly or after copper plating, to copper, and to steel which has been first coated with copper, nickel, or zinc. Where protection against corrosion is desired, the "black nickel" should be preceded by zinc plating. The wearing properties of the "black nickel" surface are largely determined by the quality of the lacquer subsequently applied.

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[1] Technologic Paper No. 190.

WAVE-LENGTH MEASUREMENTS IN ARC SPECTRA PHOTOGRAPHED IN THE YELLOW, RED, AND INFRA-RED.[6]

By F. M. Walters, Jr.

[ABSTRACT.]

FOR several years the Bureau of Standards has been conducting grating measurements in red and infra-red arc spectra by the aid of specially sensitized photographic plates to improve the data in this region and to find some element which would furnish lines suitable for wave-length standards in this region. To the measurements on 25 elements already made, the following are here added:

Element.	Region.	Number of Lines Observed.
Silver	5500—8273	6
Aluminum	5500—8774	10
Gold	5500—7510	17
Bismuth	5500—9657	27
Cadmium	5500—10,395	13
Mercury	5500—8195	16
Lead	5500—8272	14
Antimony	5500—9132	74
Tin	5500—9146	49
Zinc	5500—7799	16

The wave-length measurements are in the international system and are given to 0.01 A.

The elements were brought to luminosity by inserting a sample in copper or graphite electrodes between which the arc was maintained. The grating used had 297 lines per mm. and a 640 cm. radius. The spectra were photographed in the first order on plates sensitized with pinacyanol or dicyanin. The comparison spectrum was iron in the first, second, or third order, and in the reductions the wave-lengths established by interference methods were used.

A comparison of the wave-lengths measured for the same element by different observers shows that impurity and spurious lines must be looked for very carefully, that it is necessary to describe exactly the source of light and specify the observing conditions, and that the accuracy possible in wave-length measurements from the direct photography of normal spectra exceeds that in measurements from phosphor photography and bolometer measurements.

[6] Scientific Paper No. 411.

A STUDY OF TEST METHODS FOR THE PURPOSE OF DEVELOPING STANDARD SPECIFICATIONS FOR PAPER BAGS FOR CEMENT AND LIME.[1]

By P. L. Houston.

[ABSTRACT.]

THIS technologic paper is published in order to aid the paper-bag manufacturers to meet the requirements of the lime and cement manufacturers in obtaining a suitable paper bag in which to ship their product. It contains information relating to the methods of testing and the apparatus employed in determining the quality of paper bags for lime and cement. For this purpose representative samples of paper bags are obtained from a number of the leading bag manufacturers. These bags are given identification numbers and the following tests are performed. These tests are divided into two classes, namely, ordinary and special tests. The first class includes all tests that are ordinarily performed on paper, such as weight in pounds of the standard size ream 25 × 40—500, bursting strength in points, tensile strength in kilograms, stretch in centimetres, folding endurance in number of double folds, percentage of fibre composition, percentage of ash and percentage of rosin sizing. The second class includes certain tests that are specially appropriate for paper bags. There are three distinct tests in this class. The first is a laboratory test performed on a recording instrument and gives numerically the stresses and strains that the paper of these bags undergoes in service. This test is called a resiliency or endurance test. The second is a service test and determines the breaking strength of the paper when the bags are filled with 94 pounds of sand and dropped a distance of three feet. This test is called a drop test, and its purpose is to reproduce service conditions since a bag is often dropped while being handled. A comparison is made of the results of the drop test with the results of the above resiliency test and the same papers prove strongest in both cases. It is thus proven that the resiliency test is a very good test for showing what the paper of a bag will do in actual service, and since it is strictly a laboratory test, it is highly to be recommended. The third is also a service test and determines the strength of the adhesives used in the bags; the bags are filled with 94 pounds of sand and jolted one inch high on an ordinary foundry

[1] Technologic Paper No. 187.

jolter. This test is called a jolter test and somewhat duplicates the treatment that a bag undergoes while being jolted and jarred in shipment from manufacturer to consumer. The results of all these tests are tabulated, and from these data the very best quality bags are chosen. In the conclusions, special consideration is given this choice of best bags in determining the characteristics of a good quality bag, which are: good bursting strength, high tensile strength in both directions, high endurance or resiliency, high folding endurance, a fibre composition of not less than 50 per cent. strong manila and jute with the remainder as chemical wood, ash not over 3 per cent. and rosin sizing at least 3.5 per cent. As a final conclusion from the results of the various tests on the chosen best quality bags, these characteristics are drawn up in the form of specifications.

SOME PROPERTIES OF WHITE METAL BEARING ALLOYS AT ELEVATED TEMPERATURES.[8]

By John R. Freeman and R. W. Woodward.

[ABSTRACT.]

THE BUREAU OF STANDARDS as part of a general investigation of the properties and methods of testing the white metal bearing alloys has developed apparatus for determining their properties at elevated temperatures. This paper describes apparatus for determining the yield point and ultimate strength of these alloys in compression of temperatures up to 150° C. A similar apparatus is also described for determining the Brinell hardness at these elevated temperatures.

The results of compression tests and Brinell hardness tests obtained with this at 25° C., 50° C., 75° C., and 100° C. are given for the five following alloys:

Alloy No.	1	2	3	4	5
	per cent.	per cent.	per cent.	per cent.	per cent.
Copper.....	4.56	3.51	5.65	2.90	.....
Antimony...	4.52	7.57	6.90	10.50	10.03
Tin.....	90.02	88.92	87.36	61.55	5.02
Lead.....	absent	absent	.09	25.05	84.95
Iron.....	<.05	<.05	<.05	<.05	<.05

[8] Technologic Paper No. 188.

Alloys Nos. 1, 3, 4, and 5 are the four alloys being recommended by the S. A. E. as standard alloys.

The results of these tests show that the three tin-base alloys maintain their properties better at the elevated temperatures than either the lead base or the intermediate alloy.

The effect of the addition of up to 5 per cent. of lead on the properties of the tin-base alloys was studied and found not to influence the yield point at 25° C. or 75° C.

The yield point of the tin-base alloys is not affected by heating for six weeks at about 100° C., but the yield point is lowered in the lead-base alloy by heating for two weeks at about 100° C.

SPECTROPHOTOELECTRICAL SENSITIVITY OF PROUSTITE.*

By W. W. Coblentz.

[ABSTRACT.]

THE present investigation is a continuation of previous work on the spectrophotoelectrical sensitivity of various substances.

At 20° C. the spectrophotoelectrical sensitivity curve of proustite has a slight maximum at about 0.61μ and a marked sensitivity with a wide maximum (at about 0.3μ) in the ultra-violet.

At −170° C. the intrinsic spectrophotoelectrical sensitivity is greatly increased; but the maximum reaction is confined mainly in a sharp maximum at 0.578μ. No photoelectrical sensitivity was observed for radiation stimuli of wave-lengths extending from 0.7μ to 2μ.

Energy Losses in Commercial Hammers. E. MORRISON and R. L. PETRY. (*Physical Review*, March, 1921.)—When one body strikes another the total momentum is unchanged by the impact. The total kinetic energy is, however, less after the collision. Experiments with mechanics' hammers from a hardware store showed that those of the first grade lost 2.3 per cent., those of the second grade 5.3 per cent., and the third grade implements 9.3 per cent. Similar hammers obtained in a five-and-ten-cent store were found to lose 20 per cent. of kinetic energy. Railroad track hammers lost from 2.3 to 5.5 per cent.

G. F. S.

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* Scientific Paper No. 412.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE POSSIBLE PATHOGENICITY OF *BACILLUS BOTULINUS*.[1]

By Ruth B. Edmondson, L. T. Giltner, and Charles Thom.

[ABSTRACT.]

CALCIUM CHLORIDE injected into guinea-pigs with toxin-freed bacilli or spores of *B. botulinus* acts as an accessory factor in producing botulism. Under such conditions the behavior of *B. botulinus* is similar to that reported by Bullock and Cramer for the organisms of gas gangrene and tetanus.

On the basis of experiments tried, toxin-freed spores of the Boise strain of *B. botulinus*, when fed in sufficiently large doses to guinea-pigs, can produce the specific disease and death, while the Nevin strain similarly fed does so occasionally. A limited pathogenicity is thus indicated.

Foods suspected of containing *B. botulinus* should be destroyed, not heated and eaten.

THE DETECTION OF METHYL ANTHRANILATE IN FRUIT JUICES.[2]

By Frederick B. Power.

[ABSTRACT.]

ALTHOUGH methods for the detection or quantitative determination of methyl anthranilate in essential oils have long been in use, the isolation of the substance from such products as fruit juices in a form sufficiently pure to permit of its identification was found to involve somewhat unexpected difficulties, which, however, were ultimately overcome.

It was found that the preliminary isolation of methyl anthranilate in the requisite degree of purity could not be effected by direct extraction with ether. It is, therefore, best to first distil the fruit juice in a current of steam. The methyl anthranilate is

* Communicated by the Chief of the Bureau.

[1] Published in *Arch. Internal Med.*, **26** (1920), 357–366.

[2] Published in *J. Am. Chem. Soc.*, **43** (1921), 377–381.

then extracted from the distillate by chloroform and the solvent removed. The residue, when dissolved in dilute sulphuric acid and diazotized, is finally tested with β-naphthol or with dimethylaniline, preference being given to the former reagent on account of the greater delicacy of the reaction.

Having developed a practical and trustworthy method for the detection of methyl anthranilate in grape juice, commercial samples of this product as well as those of known purity will be examined for the presence of the respective compound. These results will be published later.

In his biography of John William Strutt, Lord Rayleigh (*Proc. Royal Soc.*, A. 695), Sir Arthur Schuster makes the following comparison of three great Victorian physicists—"Kelvin felt strongly and expressed himself forcibly. To him the mechanism of the ether and of the ultimate constituents of matter could not be otherwise than the mechanism of the gross matter he could handle in the laboratory. That was the Alpha and Omega of his convictions. Stokes was more cautious; where Kelvin was angry, he only smiled mysteriously. In purely scientific matters, and in private conversation or unreported speeches, one suspected that Stokes had something of the iconoclast in his composition, and he enjoyed being told of any experiment that could not be reconciled to current theories. Rayleigh was purely judicial, repressing his personal predilections. To put it into colloquial language, where Kelvin would say: 'This is all nonsense,' and Stokes answer: 'Perhaps, but all the same it is a hard nut for you to crack,' Rayleigh would ask, 'What is the evidence?' He did not hide his dislike of some of the modern theories, but he went far enough to admit that, if it be impossible to demonstrate experimentally the relative motion of a body and the ether, our belief in the existence of the ether must be reconsidered."

Atomic Weight of Antimony.—H. H. WILLARD and R. K. MCALPINE of the University of Michigan (*Journ. Am. Chem. Soc.*, 1921, xliii, 797–818) have made a redetermination of the atomic weight of antimony by the analysis of antimony bromide. The atomic weight was found to be 121.773.

J. S. H.

NOTES FROM THE RESEARCH LABORATORY EASTMAN KODAK COMPANY.*

A WIDE ANGLE ASTRONOMICAL DOUBLET.[1]

By F. E. Ross.

THE present lens is an outcome of the war-time activity of the Eastman Kodak Company in lens design and manufacture. A lens of 6 inches aperture and 48 inches focal length has been designed and constructed by the company for the aerial service, which passed the most rigid tests. The present lens is nearly identical with this, the difference being in the glass used, a lower index flint being substituted which enabled a complete simultaneous elimination of field curvature and astigmatism to be obtained over a total field of 25°. Correction of this kind has heretofore not been secured in any type of lens, for a total field angle greater than 10°. Thus the field of critical definition has been more than doubled in the present lens compared with the best of previous types which makes it useful for many astronomical purposes. One of these lenses has already been constructed by the Brashear Company for the Yale Observatory. The result of the test has not yet been received.

THE ORIENTATION OF THE GRAINS IN A DRIED PHOTOGRAPHIC EMULSION.[2]

By L. Silberstein.

THE problem treated in this paper consists in finding the amount of orientation and of the average efficient area of the silver halide grains (small plates) in the final dry state of a photographic emulsion spread over a film base, the distribution of the directions of the plate-normals in the initial state being haphazard. The efficient area and the final distribution law of directions are given in terms of the contraction ratio of the layer, *i.e.*, of the ratio of its final to its initial thickness.

* Communicated by the Director.

[1] Communication No. 107, published in *J. Opt. Soc. Amer.*, March, 1921.

[2] Communication No. 112, published in *J. Opt. Soc. Amer.*, March, 1921, p. 171.

Removal of Deposited Copper from a Silver Cathode.—Copper may be determined quantitatively in the electrolytic way by its deposition on a silver cathode. HOWARD WATERS DOUGHTY and BENJAMIN FREEMAN, of Amherst College (*Journ. Am. Chem. Soc.*, 1921, xliii, 700–704), have devised a novel procedure for the rapid and complete removal of the deposited copper after the analytic determination has been completed. The cathode is immersed in an ammoniacal solution of an organic compound containing a trichloromethyl or a tribromomethyl group. One solution contains ten per cent. of trichloroacetic acid dissolved in aqueous ammonia which is prepared by mixing one volume of aqua ammonia of specific gravity 0.90 and one volume of water. Another solution is obtained by dissolving either chloroform or carbon tetrachloride in a mixture of equal parts by volume of concentrated aqueous ammonia and alcohol. Approximately ten minutes are required for complete removal of the copper. Apparently three atoms of copper react with two molecules of trichloroacetic acid. This procedure may also be used for the removal of deposited cadmium and zinc from the silver cathode.

J. S. H.

Separation of Certain of the Rare Earths from Each Other.—ARTHUR C. NEISH and J. W. BURNS (*Canadian Chem. and Metal.*, 1921, v. 69–74) have devised the following procedure for the separation of thorium, cerium, neodymium, praesodymium, and lanthanum. The solution, containing these metals as nitrates, is treated with either hydrogen sulphide or sulphur dioxide to convert the cerium into the cerous condition. The solution is then boiled until any excess of the reducing agent has been expelled, and is treated in an atmosphere of carbon dioxide, with a slight excess of one of the following compounds: lead carbonate, zinc carbonate, cupric carbonate, zinc oxide, or red lead (Pb_3O_4). Thorium is thus precipitated as its hydroxide, and is removed by filtration. Sufficient potassium permanganate is added to the filtrate to oxidize the cerium to the ceric condition; the solution is heated to boiling; a slight excess of either lead carbonate, manganous carbonate, zinc carbonate, or red lead is added while stirring; and the precipitated ceric hydroxide is immediately collected by filtration. The filtrate thus obtained is treated with a slight excess of either silver oxide, magnesium oxide, or magnesium carbonate at a temperature of 60° C.; neodymium and praesodymium are precipitated, and may be separated from each other by a lengthy series of fractional precipitations with ammonia. Lanthanum is present in the filtrate from the neodymium and praesodymium, and is obtained by precipitation with sodium hydroxide.

J. S. H.

NOTES FROM THE U. S. BUREAU OF MINES.*

ESTIMATION OF PLATINUM IN ORES.

By C. W. Davis.

THE high price of platinum has stimulated prospecting for new occurrences of this metal, and the Bureau of Mines has received many inquiries concerning the commercial assay of ores for platinum. Methods in use have varied widely, and frequently results submitted by assayers and chemists have been misleading or worthless, through inexperience or use of an improper method. Technical Paper 231, recently published by the bureau, entitled "The Detection and Estimation of Platinum in Ores," summarizes the various methods for the detection of the metal and gives a selected method for the commercial estimation of platinum in ores. A short supplementary paper on "The Estimation of Small Quantities of Gold, Silver, and Platinum in Material High in Copper" has been issued in mimeographed form.

RETORT FOR ASSAYING OIL SHALES.

By L. C. Karrick.

THE BUREAU OF MINES has received many inquiries on the subject of assaying oil shales, both from individuals who desire to make their own assays while in the field and also from commercial assayers and research men. Many retorts now in use for experimental work on oil shales are suitable when used in the capacity for which they were developed. However, for convenience and accuracy in rapid assays in the field and laboratory, and for providing a basis of comparison between assays, there is need for a retort and method whose specifications are definitely fixed, and which will give results agreeing closely in duplicate determinations. The retort used by the Bureau of Mines, in the research work on oil shales now in progress at Salt Lake City, Utah, and at Boulder, Colo., was developed in the bureau's laboratories and has been found to be convenient in use and capable of yielding reproducible results.

* Communicated by the Director.

Several devices were tried by the bureau before the one now in use was adopted. It was suggested from the field retort used by Winchester and described by him in Bulletin 641 of the United States Geological Survey. Changes were made in the size of retort, the angle of take-off of the delivery tube, the style of heater, and general assembly of parts; and there were added a reflux condenser, jacket, and cover. All the parts can be easily obtained from any dealer in chemical supplies, and readily assembled by anyone. It is more fully described in a paper entitled "A Convenient and Reliable Retort for Assaying Oil Shales," recently issued by the bureau in mimeograph form.

SLATE DUST IN ASPHALT ROAD SURFACE MIXTURES.

By Oliver Bowles.

FROM 80 to 95 per cent. of the gross production of all slate quarries is discarded as waste. The Bureau of Mines has undertaken a study of the industry for the purpose of devising means of reducing the proportion of waste, and of utilizing the unavoidable waste. The latter has received special attention.

As intimations had been received from several sources that slate flour constituted a superior filler for road asphalt mixtures, an attempt was made to obtain more definite data as to its adaptability for such a use. The coöperation of manufacturers was requested, and as a result several companies offered to test the material in their experimental laboratories. Samples of finely pulverized slate were submitted for this purpose. Tests were made both on asphalt bonded briquets and on standard sheet asphalt pavement mixtures.

The results indicate that for resistance to impact slate flour is about equal to other fillers in bonded briquets, and somewhat superior in sheet surface mixtures. In cementing value it is superior to both limestone and Portland cement in asphalt bonded briquets, and intermediate between them in standard sheet surface mixture. Elutriation tests indicate that slate flour contains approximately 15 to 25 per cent. more of the fine dust that constitutes effective filler than either limestone, trap rock, or Portland cement. In volume weight slate is about equivalent to limestone, and approximately 10 per cent. superior to Portland cement. The

cost of slate flour is little more than half that of Portland cement, but its ability to compete in price with limestone is not yet established.

The tests were not sufficiently comprehensive to give conclusive results, but they are definite enough to suggest possibilities of such importance as to induce further and more extended research both by slate producers and by manufacturers of asphalt road mixtures. It is highly desirable that the conclusions reached be verified by practical tests on experimental roads.

Development After Fixation. (*P. J. A.*)—The following is important in this connection, as it refers to a discovery made about twenty years ago by Professor F. E. Nipher, of Washington University, St. Louis, Mo. In 1901, he published in the Transactions of the St. Louis Academy of Sciences the results of experiments on very long overexposure. Giving, for instance, plates that required only a fraction of a second, several hours' exposure, necessarily to a fixed object, he found that not only was the picture reversed, a fact already known, in a general way, but the development could be made in full light; in fact, must be so made for if developed in darkness the plate will fog. Nipher's experiments were repeated a few months later by members of the Photographic Section of The Franklin Institute, Philadelphia, and the results were exactly as had been described. A rapid plate, which had been given four and one-half hours' exposure, was passed around a lighted room for the examination of those present, and then developed in front of a sixteen-candlepower electric light, while another plate similarly exposed, but which had been developed in the dark-room, was fogged. The plate developed in the light, on being fixed, came out as a perfectly clear positive.

Anticipation of Daguerre. (*Photographic Jl. of Am.*, April, 1921, p. 157.)—It is asserted that in a publication, entitled "*Pfennig-Magazin,*" in the year 1840, an account is given of a process of copying copper-plate engravings, drawings and writings by contact with a prepared paper. It is claimed that five days before Arago presented to the French Academy the account of Daguerre's process, a certain Mr. Breyer deposited with the Brussels Academy a sealed package containing a statement of his first results, and requested that it should be opened at the meeting of the Academy on the 5th of October of that year. Dr. Limmer, President of the Photographic Institute of the Technologic High School at Darmstadt, is authority for the statements. Claims of this character are often made without sufficient warrant. The publication mentioned is not likely to be found in the United States; nor, indeed, outside of the country of publication. Almost all great discoveries are foreshadowed, and generally by workers who have remained comparatively obscure. Glauber (1604–1668) was aware of the fact that organic substances stained with silver nitrate will turn black when exposed to light.

Photo-Stereo-Synthesis. (*La Nature*, April 2, 1921.)—Once more the name of Louis Lumière is associated with a new and interesting optical device, in this case a method of producing the appearance of solidity without resorting to the means hitherto employed to invoke the stereoscopic effect. When one looks at a man's face not all parts are seen at the same time with equal clearness. The focus of the eyes of the observer can be changed in ranging over the face so that now the nose, now the ears are in focus. One of the marks of solidity is the necessity of the eye's varying its focus in roving over the object.

M. Lumière takes six photographs of the face. In the first the end of the nose and the moustache are sharp, while the rest of the face is hazy. In the second the plane of sharp definition has moved back to the eyes and the forehead. The features in front of this plane as well as those back of it are not clear. Thus the plane of sharp outline moves by steps from the nose to the ear. From these six negatives as many positives are made, but the latter are of small density, so that the superposition of the six transparent images gives a composite image equal in intensity to one ordinary positive image. These six positives are supported with a slight interval between them and with their planes parallel. Upon looking at the positives in a direction perpendicular to their plane and from a suitable distance a striking impression of relief is caused.

Two arrangements are described from such negatives as have been discussed. In the first the lens of the camera is translated about a line parallel to its axis, after the sharp image of the previously mentioned nose has been focussed on the plate in such manner that any line of the lens continues parallel to itself. At the same time a similar motion is imparted to the plate. When certain geometrical relations are observed the image of the nose will keep its position on the plate unchanged, while the image of the lobe of the ear, for example, will move over an area of the sensitive plate and thus will cause a blurred image. The effect of this arrangement is to reduce the depth of field of the lens. The image of the nose will be sharp, but the images of other parts of the face at different distances from the lens will be hazy. For another setting the nose will be blurred while the ear will be sharply defined. The second method depends upon the use of a pair of inverting prisms.

The ingenuity of the principle employed and its incorporation in appropriate apparatus are alike worthy of the reputation of the eminent French technician.

G. F. S.

THE FRANKLIN INSTITUTE

(Proceedings of the Stated Meeting held Wednesday, April 20, 1921.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, April 20, 1921.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership, since last report, 7.

Reports of progress were presented by the Committee on Library and the Committee on Science and the Arts.

Mr. Coleman Sellers, Jr., gave an account of the life and work of Isaiah Lukens, a noted mechanician of the early part of the nineteenth century, a charter member of the Institute, its first Vice-President and first Chairman of its Committee on Inventions. He then introduced Mr. Henry R. Towne, Chairman of the Board, The Yale and Towne Manufacturing Company, New York City, who described and exhibited an odometer made by Mr. Lukens and originally purchased from the Lukens Estate by Mr. John H. Towne, father of the speaker. He then presented the apparatus to the Institute for its collections. The Chairman expressed his appreciation of the gift on behalf of the Management and the Institute.*

The paper of the evening entitled, "The Motorship: Its Economic Position with Reference to the Oil Fired Turbine Steamer," was then presented by Dr. Charles E. Lucke, Professor of Mechanical Engineering, Columbia University, New York City. He stated that the future of the American merchant marine will be determined by the success of its cargo-carrying ships measured by transportation costs in competition with foreign vessels. The motorship has been highly developed and extensively built in Europe, but not in America. The geared steam turbine steamer has been and now is the main reliance in this country and is in competition at sea with the European motorship. Each has at present a proper but different economic position which will be determined by analysis of weights, fuel consumptions and costs. He said the machinery of both classes of vessel is still undergoing changes and the relative competitive position of these two types of vessel in the future will be determined largely by these changes and a second analysis will estimate the effects of the changes. The opinion was expressed that there will probably be always a place for both types of ship, the problem being to define the position in which each is best, by analysis of characteristics, and to estimate the comparative numbers of each required for handling world trade. The subject was illustrated by lantern slides.

After a discussion participated in by Mr. Henderson and others, including Mr. J. N. Mahoney, of New York City, who described some new improvements in the internal combustion engine recently made by Mr. Elmer E. Sperry, a unanimous vote of thanks was extended to the speaker.

Adjourned.

R. B. OWENS,
Secretary.

*The remarks of Mr. Sellers and Mr. Towne will appear in a later number of the JOURNAL

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, April 6, 1921.)

HALL OF THE INSTITUTE,
PHILADELPHIA, April 6, 1921.

MR. CHARLES W. MASLAND *in the Chair.*

The following reports were presented for final action:

No. 2749: Surface Combustion Burner. The Edward Longstreth Medal of Merit awarded to William Barton Edison, of New York.

No. 2752: Philbrin Ignition System. Dismissed without prejudice.

R. B. OWENS,
Secretary.

SECTIONS.

Electrical Section.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, March 24, 1921, at 8 o'clock, with Mr. Charles E. Bonine in the Chair.

Mr. W. E. Ruder of the Research Laboratory, General Electric Company, Schenectady, New York presented the paper of the evening entitled, "The Science of Electric Welding." A brief historical review of the subject was given and the methods and apparatus used at present in practice were described. The nature of the metal deposit was also discussed and the recent work done along the line of perfecting it. The commercial aspect of electric welding was considered from the point of view of the manufacturer and the electricity supply company. The subject was illustrated by lantern slides.

A discussion followed the reading of the paper, in which Doctors Northrup and Hering, Mr. Eglin and others took part. The thanks of the meeting were extended to the speaker.

Adjourned.

R. B. OWENS,
Secretary.

Mechanical and Engineering Section.—A meeting of the Section was held on Thursday evening, March 31, 1921, at 8 o'clock, in the Hall of the Institute. The meeting was called to order by Mr. Coleman Sellers, Jr. Dr. Gordan F. Hull of the Technical Staff, Office of the Chief of Ordnance, War Department, Washington, D. C., presented the paper of the evening entitled "Some Applications of Physics to Ordnance Problems."

Experiments to determine the law of air resistance were described as well as the results obtained by holding a projectile in an air stream and measuring the force upon it. Photographs were shown of the disturbed air about a projectile and the underlying physical principles involved. New apparatus and new methods for determining the retardation of a projectile were described and an account was given of experiments to determine the stability

of a shell. The subject of pressures in guns and the resulting expansion as well as causes contributing to the bursting of guns were also given consideration. The subject was illustrated by lantern slides.

After a discussion the thanks of the meeting were conveyed to the speaker. Adjourned.

R. B. OWENS,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, April 13, 1921.*)

RESIDENT.

MR. LEONARD T. BEALE, 705 Lafayette Building, Philadelphia, Pennsylvania.
MR. J. E. BREWER, West Conshohocken, Pennsylvania.
MR. RODRICH BOEHMKE, 827 Spring Garden Street, Philadelphia, Pennsylvania
MR. EARL R. MILLER, Electric Storage Battery Company, Philadelphia, Pennsylvania.
MR. EDWARD W. PARKER, 437 Chestnut Street, Philadelphia, Pennsylvania
DR. HAAKON STYRI, S. K. F. Research Laboratory, Front and Erie Avenue, Philadelphia, Pennsylvania.

NON-RESIDENT.

MR. A. R. SANDT, 716–718 Metropolitan Life Building, Minneapolis, Minnesota.

CHANGES OF ADDRESS.

MR. W. E. FLETCHER, Atlas Powder Company, Wilmington, Delaware.
MR. RICHARD P. HARVEY, R.F.D. No. 1—Box 16, San Mateo, California.
MR. H. M. KAUFMANN, Mutual Chemical Company of America, 110 William Street, New York City, New York.
MR. GUSTAV LINDENTHAL, 7 Dey Street, New York City, New York.
MR. FRED J. MILLER, Stockton, New Jersey.
MR. WILLIAM S. MURRAY, 709 Sixth Avenue, New York City, New York.
MR. G. F. OTT, 325 Hansberry Street, Philadelphia, Pennsylvania.
MR. W. L. PLACK, S. W. Corner Twelfth and Locust Streets, Philadelphia, Pennsylvania.
MR. G. BERKELEY REED, 182 Broad Street, New London, Connecticut.
MR. CHARLES E. RICHARDSON, Charles E. Richardson & Co., 18 E. 60th Street, New York City, New York.
MR. W. F. RITTMAN, Salem, Ohio.
MR. JOSEPH B. ROHRMAN, 15 Aronimink Place, Drexel Hill, Pennsylvania
MAJOR R. A. WIDDICOMBE, 26 North Jefferson Street, Chicago, Illinois.

NECROLOGY.

Mr. Howard S. Graham, 435 Chestnut Street, Philadelphia, Pennsylvania.
Mr. Jacob Hasslacher, 70 Westland Avenue, Boston, Massachusetts.
Mr. J. S. Whitney, 1509 Arch Street, Philadelphia, Pennsylvania.

LIBRARY NOTES.

PURCHASES.

American Annual of Photography for 1921.
American Electrochemical Society Transactions. Vol. 36, 1920.
CHAMBERS, T. W.—Gyroscopic Compass. 1920.
Chemical Engineering Catalog. 1920.
Chemists Year Book. 1920.
DAW, A. and Z. W.—Compressed Air Power. No date.
EDDINGTON, A. S.—Space Time and Gravitation. 1920.
FOERSTER, E.—Johows Hilfsbuch für den Schiffbau. 1920.
HERIOT, T. H. P.—Manufacture of Sugar from Cane and Beet. 1920.
HOLMES, A.—Nomenclature of Petrology. 1920.
IVENS, E. M.—Pumping by Compressed Air. 1920.
JELLINCK, K.—Lehrbuch der Physikalischen Chemie. 1914.
KERSHAW, B. C.—Use of Low Grade and Waste Fuels for Power Generation. 1920.
MONCKTON, T. A.—Hydrogen Manual. 1919.
Photograms of the Year. 1920.
RIDEAL, E. K.—Ozone. 1920.
RIDEAL, S.—Carbohydrates and Alcohol. 1920.

GIFTS.

Ottonis de Guericke Experimenta Nova (ut Vocantur) Magdeburgica de vacuo spatió Primùm à R. P. Gaspare Schotto, è Societate Jesu, & Herbipolitanæ Academiæ Matheseos Professore: nunc verò ab ipso Auctore Perfectiùs edita, variisque aliis Experimentis ancta . . . 249 pages, illustrations, folio. Amstelodami, 1672.

(From MR. WILLIAM FORSYTH.)

Acheson Graphite Company, Electric Furnaces. Niagara Falls, New York, 1920. (From the Company.)

Aldrich Pump Company, Hydraulic Machinery. Allentown, Pennsylvania, 1920. (From the Company.)

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American Foundry Equipment Company, American Sand Blast Equipment. New York City, New York, 1920. (From the Company.)

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Armstrong Cork and Insulation Company, Nonpareil Insulating Brick. Pittsburgh, Pennsylvania, 1920. (From the Company.)

Atlantic Refining Company, The Story of Motor Oils. Philadelphia, 1920. (From the Company.)

Atmosphere Conditioning Corporation, Bulletin Nos. 120 and 450. Philadelphia, Pennsylvania, 1920. (From the Corporation.)

Automatic Fuel Saving Company, Automatic Combustion Control. Philadelphia, Pennsylvania, 1920. (From the Company.)

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Cleveland Twist Drill Company, Handbook for Drillers. New York City, New York, 1920. (From the Company.)

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De Laval Steam Turbine Company, Centrifugal Pumps. Trenton, New Jersey, 1920. (From the Company.)

Denver Rock Drill Manufacturing Company, Waugh "90" Drills. Denver, Colorado, 1920. (From the Company.)

Donnelly Systems Company, Steam Circulation. New York City, New York, 1920. (From the Company.)

Duff Manufacturing Company, Catalogue No. 104. Pittsburgh, Pennsylvania, 1920. (From the Company.)

Erie Foundry Company, Erie Steam Hammers. Erie, Pennsylvania, 1920. (From the Company.)

Fastfeed Drill and Tool Corporation, Catalogue No. 14. Toledo, Ohio, 1920. (From the Corporation.)

Flory, S., Manufacturing Company, Catalogue on Flory Hoists. Bangor, Pennsylvania, 1920. (From the Company.)

Fort Wayne Engineering Company, Bulletin Nos. 5009 and 5010. Philadelphia, Pennsylvania, 1920. (From the Company.)

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Great Britain Meteorological Office, Report of Proceedings of Paris Conference, 1919. London, England, 1921. (From the Director.)

Hanna Engineering Works, Catalogue No. 10. Chicago, Illinois, 1920. (From the Works.)

Hagan Corporation, The Hagan System Boiler Regulation. Pittsburgh, Pennsylvania, 1920. (From the Corporation.)

Haiss, Geo., Manufacturing Company, Incorporated, Booklet No. 1020. New York City, New York, 1920. (From the Company.)

Harris Brothers Company, Structural Steel. Chicago, Illinois, 1920. (From the Company.)

Harvard College Observatory, Circular Nos. 222–223. Cambridge, Massachusetts, 1920. (From the Observatory.)

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Illinois Stoker Company, Catalogue "L." Alton, Illinois, 1920. (From the Company.)

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McVicker Engineering Company, Graphic Production Control. Minneapolis, Minnesota, 1920. (From the Company.)

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BOOK NOTICES.

JOURNAL OF INDIAN INDUSTRIES AND LABOUR. Vol. 1, Part 1. Published by order of the Government of India. Calcutta, February, 1921.

This is a new venture, in the form of a very substantial and well printed issue, octavo size, containing 111 pages and 7 full plates, the latter illustrating an extended article on the Calcutta Research Tannery. The text, as will be expected, relates almost entirely to industrial questions in India. Some of these are suggestive of our own troubles, such as "Trade Disputes in Bengal." The only article directly relating to chemistry is on "Clove oil from clove stems." From this we learn that Africa is the home of clove production, the supply coming principally from Zanzibar and Pemba. In these two islands about 52,000 acres are under cultivation. The output amounts to many millions of pounds, and for the season of 1918–19 the total yield is said to have been nearly 29,000,000 pounds. Many of the trees are nearly a century old. The article, which is by S. T. Gadre, industrial chemist to the Government, United Provinces, Cawnpore, states that the oil distilled from the clove stems contains 95 per cent. of eugenol, so that it is a valuable addition to our supply of that compound.

It seems not to be stated at what intervals the parts will be issued, but the volume will consist of four parts and is priced at Rs 4–8–0, a statement which might have been translated in some equivalent in the money of western Europe.

HENRY LEFFMANN.

THE HEALTH OF THE INDUSTRIAL WORKER. By Edgar L. Collis, M.A., M.D., and Major Greenwood, M.R., C.P. Containing a chapter on Reclamation of the Disabled, by Arthur J. Collis, M.A., M.D. With an introduction by Sir George Newman, M.D. 8vo. xvi–438 pages and index. Philadelphia, P. Blakiston's Son and Co. Price $7.00 net.

The diseases that are more or less directly due to occupation have been attracting much attention of late years. Times have changed since those in which the state and the employer considered it none of their affair to take care of the health, moral or physical, of workingmen and workingwomen.

Much of the progress in this field has probably been due to the natural evolution of social conditions, but not a little of it has been the result of struggle against selfishness, struggle organized and carried out by devoted men and women who earned much obloquy by their efforts. In many fields of work much still remains to be done, and there is no denying the fact that workers of both sexes are still largely to blame for the accidents and diseases that affect them, for they often neglect the safety rules that are advised and disregard the safety appliances that are provided.

The book begins with a highly interesting history of industrial conditions in early England. The conclusion is drawn that until the beginning of the 18th century, industry, apart from agriculture, had no appreciable effect upon the health of the nation. It is generally agreed that the invention of the steam engine developed the factory system, and made a profound change in England, and later, in other parts of the world. It is true that, centuries before, occasional instances of collection of numerous workers in one industry and under one employer are noted, but they are rare. It is stated, for example, that in the time of Henry VII, a clothier, known as "Jack of Newbury," employed over 1000 persons, but this is merely an isolated instance. The only factories in early England were the parish water or wind-mills at which grain was ground.

Reference is made to the commonly received view that the first half of the eighteenth century was the golden age of English industry, in which its material advantages were happily combined with health-giving attributes. Macaulay, indeed, opposed such view, and, in one of his essays, ridiculed Robert Southey's glorification of contrast between "rose bushes and poor rates" as against "steam engines and independence." Macaulay considered the latter a preferable condition. He, however, spoke in 1846, in Parliament, strongly in favor of reform in the condition of factory workers. Unfortunately, the data for judging of the mortality and morbidity in these earlier periods are scanty, but what information is at hand shows that the average duration of human life has increased. How far this increase is due to smaller families, and to lowered infant mortality, cannot be definitely answered. The authors consider proved the fact that the data at hand show that the sanitary conditions of the hand-laboring population changed for the worse in the industrial revolution and remained for fifty years a disgrace to civilization.

The course of state control through the centuries is traced in an interesting manner, from the Ordinance of Laborers (1349) remedying conditions brought about by the great plague, followed by other laws to secure better enforcement of the original one. The Statute of Apprentices was passed in Elizabeth's reign. A striking feature of this act was the regulation of the hours of labor, not by limitation as at the present time, but by imposition. In summer the work began at 5 A.M. and continued until after 7 P.M. The trained workman was forbidden to change his trade or to leave the district in which he was employed. Later, came the Poor Laws, so dark a blot upon England's legislation the iniquities of which are so well known to readers of Dickens' novels.

It would be interesting to go in this manner over the whole work for it is crowded with data of the most striking and valuable nature, but space

does not permit such extensive consideration. One fact may be mentioned, that is interesting in these days, when so many men have been maimed in war. Mock (quoted from his work on Industrial Medicine and Surgery) states that one concern found advantage in employing men who had lost a leg or an arm, giving several reasons which are set forth for this result. Mock is also quoted to the effect that if the casualty list of industry could be printed every day in the papers, the people of the country (U. S.) would be appalled at the figures. In one year alone it is said the casualties are over four times as large as the entire casualties of the American troops on the battle fields of Europe. It must, however, be borne in mind that the number of persons employed in industries far exceeds the number in the A. E. F. at its greatest size.

As an example of the care and thoroughness with which the work has been compiled, the chapter on the bearing of the use of alcohol upon the health and efficiency of workers is well worth reading. Some of the more frequently heard claims, *pro* and *con*, are shown to be unworthy of consideration. The opinion expressed is that alcohol is not necessary to the human being in health, and that its use diminishes efficiency in some industries.

The work is based on extensive consultation of authorities and large personal experience. Excellently printed on good paper, it constitutes a most useful addition to the literature of a subject which is second to none in importance at the present time.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 99, Accelerations in Flight, by F. H. Norton and E T. Allen. 8 pages, illustrations, quarto. Washington, Government Printing Office, 1921. This report deals with the accelerations obtained in flight on various airplanes at Langley Field. The instrument used in these tests was a recording accelerometer of a new type designed by the technical staff of the National Advisory Committee for Aeronautics. The instrument consists of a flat steel spring supported rigidly at one end so that the free end may be deflected by its own weight from its neutral position by any acceleration acting at right angles to the plane of the spring. This deflection is measured by a very light tilting mirror caused to rotate by the deflection of the spring, which reflected the beam of light onto a moving film. The motion of the spring is damped by a thin aluminum vane, which rotates with the spring between the poles of an electric magnet. Records were taken on landings and take-offs, in loops, spins, spirals, and rolls. It was found that the loading in a fairly heavy landing reached a maximum of 5 g., in a loop it reached a maximum of about 3.7 g., in a spin a maximum of about 3 g., while in a roll it attained the value of 4.2 g., showing that this maneuver puts a greater strain on the machine than any other. A JN–4H was pulled as suddenly as possible out of a dive at 50, 60, 70 and 80 miles an hour. The records show that the time elapsed between pulling the stick back and reaching the maximum acceleration was independent of the air speed and amounted to about 0.9 seconds. These accelerations are slightly lower than the theoretical accelerations that would be obtained if the machine were suddenly turned to the angle of maximum lift. It was also found that an airplane had a certain definite period of vibration

which could be excited by the engine, but which was not at all dependent upon it, as the vibrations were nearly as evident when the machine was gliding with a dead stick. This period of vibration appeared to be inversely proportional to the weight of the machine. It is concluded from these tests that in no reasonable stunting would the load in flying ever exceed a factor of four and one-half times the normal stress.

Report No. 101, The Calculated Performance of Airplanes Equipped with Supercharging Engines, by E. C. Kemble, Harvard University. 52 pages, diagrams, quarto. Washington, Government Printing Office, 1921.

In part 1 of this report are presented the theoretical performance curves of an airplane motor equipped with a supercharging compressor. Means for estimating the temperature rise in the compressor are outlined. Since the compressor will be designed for a definite normal pressure ratio, the gross power output under normal conditions is easily computed when the intake temperature is known. In the case of a gear-driven compressor, the net power is obtained by subtracting the power absorbed by the compressor from the gross power. For use in determining the size and power absorption of the compressor needed in a given case, a formula for the variation of the volumetric efficiency of the motor with intake temperature and exhaust pressure is derived.

A graphical method is outlined whereby performance curves for either type of motor-compressor unit at all speeds and altitudes may be laid out with the aid of assumed compressor characteristics. Comparative performance curves for a Liberty motor operating with a turbine-driven compressor, a gear-driven compressor, and without supercharging, are derived in an illustrative calculation.

Part 2 of this report presents an estimation of the performance curves of an airplane fitted with a supercharging motor. If the heat leak from gas turbine and exhaust pipes to the water jackets is prevented, and the cooling system is kept under constant pressures, no additional radiator equipment should be required when a supercharging compressor is fitted to an airplane engine.

In an illustrative example horizontal flight speed and maximum climbing speed curves are worked out for the Lepere two-seater fighter when equipped with supercharging and non-supercharging engines, and with both fixed and variable pitch propellers.

A supercharging installation suitable for commercial use is described, and it is shown that with the aid of the compressor a great saving in fuel and a considerable increase in carrying capacity can be effected simultaneously.

In an appendix the writer derives a theoretical formula for the correction of the thrust coefficient of an airscrew to offset the added resistance of the airplane due to the slip-stream effect.

Report No. 105, Angles of Attack and Air Speeds During Maneuvers, by E. P. Warner and F. H. Norton. 12 pages, illustrations, quarto. Washington, Government Printing Office, 1921. In seeking further information as to the nature of maneuvers and as to the maneuverability characteristics of airplanes, continuous measurements of the angles of attack and air speeds at several points along the wings have been made during spins and loops. Very striking results have been obtained with reference to the rolling velocity and the distribution of load in spins and the variation of the angle of attack in loops, a surprisingly large range of angle being experienced during slow loops.

PUBLICATIONS RECEIVED.

U. S. Bureau of Mines: Bulletin 185, Pennsylvania Mining Statutes, Annotated by J. W. Thompson. 1221 pages, 8 vo, price $1.00. Bulletin 195, Underground Conditions in Oil Fields, by A. W. Ambrose. 238 pages, illustrations, plates, diagrams, maps, 8vo, price 65 cents. Bulletin 198, Regulation of Explosives in the United States, with Especial Reference to the Administration of the Explosives Act of October 6, 1917, by the Bureau of Mines, by Charles E. Munroe. 45 pages, 8vo, price 10 cents. Bulletin 205, Flotation Tests of Idaho Ores, by Clarence A. Wright, James C. Parmelee and James T. Norton. 70 pages, plates, 8vo, price 25 cents. Plan for Conducting Work Under Operating Regulations to Govern the Production of Oil and Gas Under the Act of February 25, 1920. 20 pages, diagrams, 8vo, price 5 cents. Technical Paper 269, Analysis of Iowa Coals, by George S. Rice, A. C. Fieldner and F. D. Osgood. 28 pages, 8vo, price 5 cents. Washington, Government Printing Office, 1920–1921.

Canada Department of Mines, Mines Branch: Preliminary Report on the Mineral Production of Canada During the Calendar Year 1920, prepared by John McLeish, B.A., Chief of the Division of Mineral Resources and Statistics. 24 pages, 8vo. Ottawa, King's Printer, 1921.

La physique des Rayons X, par MM. R. Ledoux-Lebard et A. Dauvilliers. 441 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie., 1921.

The New Philosophy of Modern Science, by W. W. Strong, B.S., Ph.D. 194 pages, 8vo. York, Pa., Kyle Printing Company, 1920. Price $4.50.

Oil Fuel: Its Supply, Composition, and Application, by Edward Butler. Fourth edition, revised and greatly enlarged. 310 pages, illustrations, 12mo. London, Charles Griffin & Company, Ltd.; Philadelphia, J. B. Lippincott Company, 1921.

The Clayworker's Hand-Book: A Manual for All Engaged in the Manufacture of Articles from Clay, by Alfred B. Searle. Third edition, revised, enlarged and largely rewritten. 381 pages, illustrations, 8vo. London, Charles Griffin & Company, Ltd.; Philadelphia, J. B. Lippincott Company, 1921.

Historical Review of the Object, Organization and Activities of the Chemical Alliance, Inc., During the World War, 1917-1918. 82 pages, 8vo. New York, The Chemical Alliance, 1920.

The Kiln Drying of Lumber, a practical and theoretical treatise, by Harry Donald Tiemann, M.E., M.F. 3rd edition, 318 pages, illustrations, plates, diagrams, 8vo. Philadelphia, J. B. Lippincott Company, 1920. Price $4.50.

Cam Design and Manufacture, by F. B. Jacobs. 121 pages, illustrations, 8vo. New York, D. Van Nostrand Company, 1921. Price $2.00.

Ammonia and the Nitrides, with Special Reference to Their Synthesis, by Edward B. Maxted, Ph.D., B.Sc. 116 pages, illustrations, 12mo. Philadelphia, P. Blakiston's Son and Company, 1921. Price $2.00.

The Distribution of Scientific Information in the United States, by Robert B. Sosman. 99 pages, 8vo. Reprinted from the *Journal of the Washington Academy of Sciences*, vol. ii, No. 4, February 19, 1921.

Mellon Institute of Industrial Research of the University of Pittsburgh. Eighth Annual Report on the Industrial Fellowships of the Mellon Institute, by Raymond F. Bacon, Director, for the Fiscal Year Ended February 28, 1921. 19 pages, illustrations, 8vo. Pittsburgh, Pa., 1921.